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TRANSACTIONS OF THE ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

ADELAIDE

PUBLISHED AND SOLD AT THE SOCIETY'S ROOMS
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BY T. HARVEY JOHNSTON AND S. J. EDMONDS

Summary

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AUSTRALIAN ACANTHOCEPHALA
No. 8

By T. Harvey Johnston and S. J. Edmonds*

[Read 13 July 1950]

SUMMARY

This paper deals with three species: (1) *Mediorhynchus corcoracis* n. sp. from *Corcorax melanorhamphus* from Queensland, New South Wales and South Australia; it was also recognised from *Corvus bennetti* from South Australia. The parasite is near *M. tenuis* Meyer but differs in size and in having 12 spiral rows each containing 11-13 hooks. (2) *Arhythmorhynchus frassoni* (Molin) is recorded from a sea curlew. *Numenius cyanopus* from Central Queensland coast. (3) *Longicollum pagrosomi* Yamaguti was found in a bream, *Mylio australis* (Sparidae) from the lower Brisbane River. It was known previously from Japanese fish.

Parasite	Host
Mediorhynchus corcoracis n. sp.	*Corcorax melanorhampus* Vieillot *Corvus bennetti* North
Arhythmorhynchus frassoni (Molin 1858)	*Numenius cynopus* Vieillot
Longicollum pagrosomi Yamaguti 1935	*Mylio australis* Gunther

All the measurements given in this paper were made on specimens cleared in methyl salicylate. Type material has been deposited in the South Australian Museum.

Mediorhynchus corcoracis n. sp.
(Fig. 2-9)

Numerous specimens of this parasite, varying in size from the larval to the adult form, have been found on a number of different occasions in the intestine of *Corcorax melanorhampus* (type host). Most of the bird hosts were from New South Wales; one was from the Upper Burnett River, Queensland (collected by the late Dr. T. L. Bancroft); and we have found it in four *Corcorax* collected at Elwomple, South Australia, by Mr. F. Jaensch. Some parasites obtained by Professor J. B. Cleland from a crow, *Corvus bennetti,* near Oodnadatta, South Australia, were identified by us as belonging to the same species. About 80 specimens were available for examination.

Adult Form

The worms are long and slender and the body of many specimens is flexed towards the anterior and posterior extremities. The largest males are 25 - 33 mm. long, and the females 42 - 63 mm. The maximum width (a) anteriorly in the males is 0·45 mm. and in the females 0·50 mm.; (b) in the mid-body region of males, 0·7 - 1·4 mm. and of females 0·8 - 1·3 mm.; and (c) posteriorly 0·7 mm. in both sexes. The armed portion of the proboscis in the male is 0·62 - 0·68 mm.

* University of Adelaide.

long, and in the female 0·64 - 0·75 mm. long. There is an unarmed neck 0·10 - 0·14 mm. long. The proboscis and neck of most specimens resemble in shape a truncated cone. The armed portion of the proboscis consists of two parts; an anterior portion which bears 12 spiral rows of 11-13 large hooks per row and a posterior portion which bears 12 spiral rows of about 10 - 12 smaller and more spiniform hooks, placed rather irregularly towards the neck. The width of the anterior region of the proboscis is 0·19 - 0·24 mm.; at the junction of the two sets of hooks it is 0·28 - 0·38 mm.; and at the neck region it is 0·37 - 0·44 mm. The size and shape of some of the hooks is shown in fig. 7.

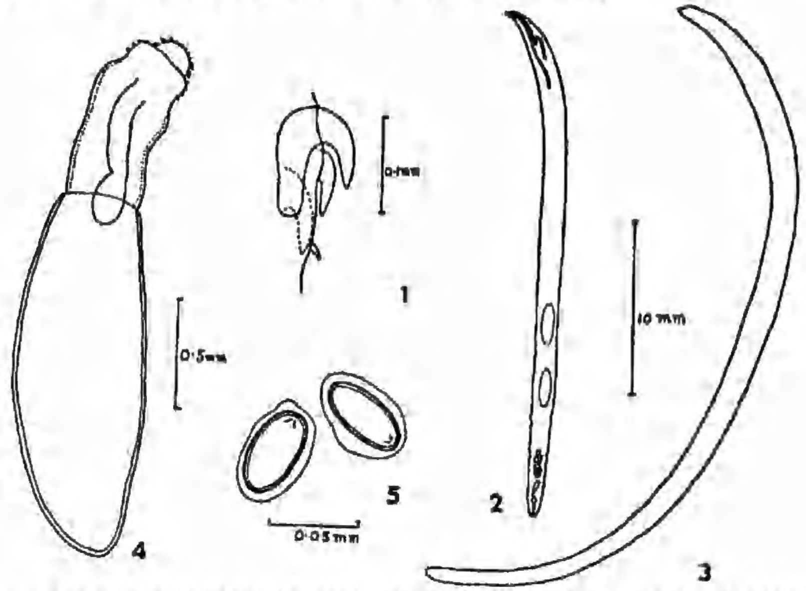

Fig. 1, *Arhythmorhynchus frassoni*, largest hook on ventral side of proboscis.
Fig. 2-5, *Mediorhynchus corcoracis:* 2, male; 3, female (to same scale as fig. 2); 4, larva emerging from cyst; 5, ripe eggs.

The proboscis sheath is 0·75 - 1·04 mm. long and arises in the proboscis at the junction of the two sets of hooks. The sheath is divided into two portions by the proboscis retractor. There are two long and slender lemnisci, the maximum dimensions of which are 4·0 mm. in length and 0·12 in width. They contain numerous large nuclei. In none of the male specimens examined do they extend as far back as the testes, as is the case with *Mediorhynchus tenuis* Meyer 1931. The body wall is thick and the lacunar system consists of a long horizontal canal from which arise numerous circular vessels.

Two testes, 1·6 - 2·6 mm. long and 0·4 - 0·7 mm. wide, are placed in tandem in the posterior half of the worm. They are of about equal size. There are eight elliptical to spherical cement glands placed very closely together. One specimen seems to possess nine glands. The male genital opening is terminal.

The female genital structure in the largest female is about 1·9 mm. long. Elliptical eggs mounted in balsam are 50 - 58μ long and 28 - 36μ wide (fig. 5).

Larval form

A number of larvae just emerging from the cyst stage were also included in the material from *Corcorax melanorhamphus*—which is an insectivorous bird. In most cases the neck and a partly everted proboscis had been freed from the cyst case. The maximum length of these larvae was 2·20 - 2·71 mm. The cyst case is elliptical. We estimate that its length would be 1·6 - 1·9 mm., and its width 0·53 - 0·66 mm.

SYSTEMATIC POSITION

This species is very close to *Mediorhynchus tenuis* Meyer (1931, 68). For some time we thought that we might be examining specimens of that species larger than those described by Meyer. Our parasites, however, differ significantly from *M. tenuis* in the number of proboscis hooks. *M. tenuis* is armed with 12 spiral rows of 9 hooks per row, while our specimens have 12 spiral rows of 11 - 13 hooks per row. No fully everted proboscis of our specimens bears rows of only 9 hooks. The anterior portion of the proboscis of *M. corcoracis* is a more heavily armed structure than that shown in fig. 8 of Meyer's description of *M. tenuis*. The male specimens of our species are much larger than those of Meyer's species and in no specimen do the lemnisci extend as far as the testes.

ARHYTHMORHYNCHUS FRASSONI (Molin 1858)

(Fig. 1)

Three male specimens of this species were found in 1910 in the intestine of a sea curlew, *Numenius cyanopus*, from Gladstone, Queensland. The parasites are long and slender, the longest measuring 27 mm. The body just posterior to the region which contains the lemnisci is swollen most noticeably and is 0·4 - 0·7 mm. wide. The swelling contains two testes placed almost in tandem. The remainder of the body is cylindrical, except the posterior portion which is broader and slightly flattened. The proboscis of none of the specimens was completely everted. One, however, was about seven-eighths everted and we consider that its armed portion when fully everted would be about 0·9 mm. long. It is swollen slightly near its middle where it is 0·30 mm. wide. The proboscis bears numerous hooks, seventeen being visible in each row, and we estimate that when the proboscis is fully extended each row would show about 20 hooks. The differentiation in the size and shape of the hooks is most marked. Those at the anterior end of the proboscis are smaller and possess recurved rooting processes. A few hooks on the ventral side of the swollen region of the proboscis are large and prominent and possess strong rooting processes. The posterior hooks are longer and more slender and their axis makes an angle of almost 90° with the axis of the proboscis. The anterior region of the body bears spines. These extend much further along the ventral surface of the worm than along the dorsal. The cement glands are very long and are pressed closely together. Our specimens agree closely with the accounts given by Lühe (1911) and Meyer (1933, 93). Saefftigen's pouch is 1·4 - 1·7 mm. long.

This species has previously been reported from *Numenius arquatus*, *N. tenuirostris* and other birds in Europe.

LONGICOLLUM PAGROSOMI Yamaguti 1935

(Fig. 10)

Three male specimens of this parasite were identified in some material obtained from the intestine of a bream, *Mylio australis* (Sparidae), caught in the Brisbane River, Queensland, in 1918. The length of the cylindrical body varies from 4·9 - 5·1 mm. All possess a very long neck, at the anterior extremity of which is an armed proboscis. The combined length of the neck and proboscis is 4·7 - 5·6 mm. The anterior portion of the proboscis is swollen into a spherical structure which was firmly embedded in the intestinal wall of the host. One proboscis had already been freed from the tissue of the host and was badly damaged. One had completely collapsed and the hooks of the other were disarranged when the remaining two specimens were dissected out by one of us. The proboscis of the best preserved specimen is 0·85 mm. long and consists of a

bulb about 0·40 mm. in diameter and a cylindrical portion about 0·45 mm. long and 0·2 mm. wide. In size and shape the proboscis of our specimen resembles very closely that of *Spirorhynchus alemniscus* Harada 1935, as shown in fig. 9 of Harada's description. We have not been able to determine with certainty the number and arrangement of proboscis hooks. There appear to be about 12 longitudinal rows of about 11 - 13 hooks per row. The double-walled proboscis sheath is long and arises just posterior to the last proboscis hook.

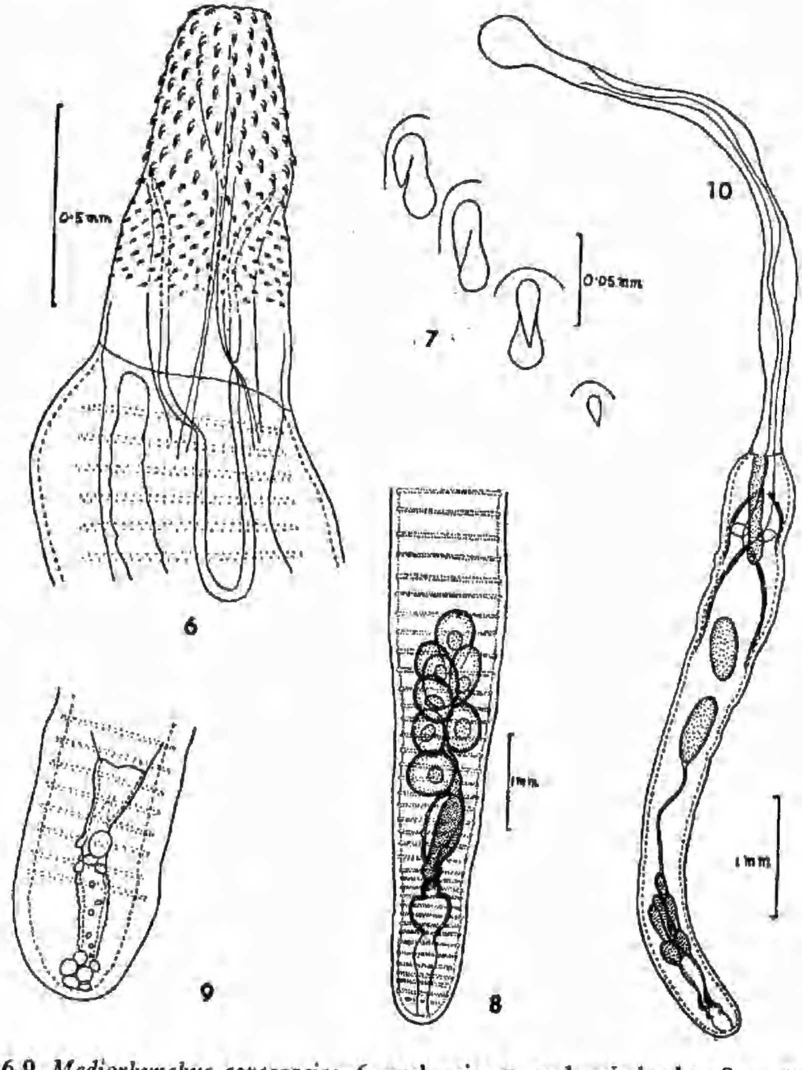

Fig. 6-9, *Mediorhynchus corcoracis:* 6, proboscis; 7, proboscis hooks; 8, posterior region of adult male; 9, posterior region of young female.
Fig. 10, *Longicollum pagrosomi,* male.

The maximum diameter of the body is at the anterior region of the parasite and is 0·53 - 1·1 mm. An elliptical mass is present near the posterior extremity of the proboscis sheath. Two lemnisci, arising at the junction of the body and the neck, are present in one specimen and are 0·8 mm. long. The body wall is thick and the lacunar system reticular. Two oval testes, 0·49 - 0·63 mm. long and 0·23 - 0·28 mm. wide, are placed obliquely in tandem. There are six cement glands which appear to consist of 3 pairs. The most posterior pair are elliptical,

the others are much longer. Each gland communicates with the bursa by means of its own slender duct, very much like the ducts in *Tenuiproboscis misgurni* Yamaguti 1935.

Our specimens agree in most details with those of *Spirorhynchus alemniscus* Harada 1935. Yamaguti (1939), however, considered this species as synonymous with *Longicollum pagrosomi* described by him in the same year (1935, 257), from the upper part of the large intestine of *Pagrosomus unicolor,* the larval stage occurring in many other Japanese fish. The proboscis of our specimens with a small terminal bulb resembles that of Harada's material very closely. Yamaguti's species possesses a short cylindrical proboscis. Well developed lemnisci were observed in one of our specimens. Harada's material was obtained from *Scatophagus argus* and *Lutianus russelli* from Formosa; Yamaguti (1935) reported immature and mature forms from various marine fishes including *Sparus longispinis.*

Harada created a family, Spirorhynchidae, to receive his genus (1935, 20). Yamaguti placed his genus *Longicollum* along with *Pomphorhynchus* and *Tenuiproboscis* in the Pomphorhynchidae (1939, 328), and stated that Harada's *Spiracanthorhynchus* (sic) was a synonym. Strand (Folia Zool. Hydrobiol., Riga, 1942, 388) pointed out that *Spirorhynchus* Harada was preoccupied by Da Cunha in 1915, and accordingly renamed it *Spirorhynchodes.* Hence we place in the synonymy of *Longicollum* Yamaguti 1935 the following:—*Spirorhynchus* Harada nec Da Cunha, *Spiracanthorhynchus* Yamaguti (error for *Spirorhynchus*) and *Spirorhynchodes* Strand 1942; and Spirorhynchidae Harada as a synonym of Pomphorhynchidae Yamaguti (1939, 328).

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NOTES ON THE LEPIDOPTERA OF THE NORTHERN TERRITORY OF AUSTRALIA, WITH DESCRIPTION OF A NEW SPECIES

BY F. M. ANGEL

Summary

This paper contains a list of sixty-three species of Rhopalocera collected in the Northern Territory April-May 1948 by the author. There are several species not previously recorded from the Territory, including two new to science. These new species have been described, and also a new Castniidae (Sub-order Heterocera), under the following names:- Ogyris hewitsoni parsonsi – A variable race from central Australia, bred from larvae. Suniana larrakia – One specimen from Darwin. Description and notes by L. E. Couchman, F.R.E.S. Synemon wulwulam – A new clubbed-antennae moth from Pine Creek. Types are figured on a photographic plate.

NOTES ON THE LEPIDOPTERA OF THE NORTHERN TERRITORY OF AUSTRALIA, WITH DESCRIPTION OF NEW SPECIES

By F. M. Angel

[Read 13 July 1950]

SUMMARY

This paper contains a list of sixty-three species of Rhopalocera collected in the Northern Territory April-May 1948 by the author. There are several species not previously recorded from the Territory, including two new to science. These new species have been described, and also a new Castniidae (Sub-order Heterocera), under the following names:—

Ogyris hewitsoni parsonsi—A variable race from Central Australia, bred from larvae.

Suniana larrakia—One specimen from Darwin. Description and notes by L. E. Couchman, F.R.E.S.

Synemon wulwulam—A new clubbed-antennae moth from Pine Creek.

Types are figured on a photographic plate.

DISCUSSION

During the months of April and May, 1948, Mr. F. E. Parsons and the writer spent five weeks on a collecting trip between Adelaide, South Australia, and Darwin, Northern Territory, during which a systematic survey was made of the Rhopalocera of the Northern Territory, along and within a short distance of the Stuart Highway.

Although in the aggregate a lot of entomological material has been collected in the Darwin area, very little appears to have been published about it; so the object of this paper is to record the species collected in the various localities visited during the above mentioned trip, in the hope that it may add a little to our knowledge of the distribution of the Australian butterflies in the less frequented parts of the North.

The time of the year, April 15 - May 10 1948, was after the wet season, and during the whole trip no rain was experienced. However, the roads to Daly River and Alligator River were reported to be impassable, which made a contemplated visit to those parts impracticable. Consequently the collecting about Darwin was confined to short daily trips.

As might be expected very little insect life was in evidence in the dry country between Alice Springs and Elliott, and it was not until the better watered parts of the Northern Territory were reached that the tropical species began to appear.

In all, sixty-three species of Rhopalocera were recorded during the trip, including two new species, as well as a number of Heterocera.

In the preparation of this paper, the author acknowledges the very great help he has received from the following gentlemen:—Mr. N. B. Tindale, of the South Australian Museum, for his kindness in preparing the photographic plate and assistance in the identification of species; Mr. L. E. Couchman, F.R.E.S., of Hobart, who so willingly undertook the description of the new species of *Suniana* and the examination of the specimens of the difficult Subfamily Hesperiinae, involving much bibliographical research. His interesting notes and description are included as an addendum to this paper. Special thanks are also due and hereby acknowledged to Mr. F. E. Parsons, who collaborated in collecting material and generously provided the motor car for the trip.

Order LEPIDOPTERA
Suborder RHOPALOCERA

DANAIDAE.

Danaus chrysippus petilia (Stoll) 1790.

This widely distributed species was abundant at Darwin, and was observed at Elliott, Katherine, Adelaide River and Roper River.

Danaus affinis affinis (Fabricius) 1775.

Common at Darwin and Manton River, also occurs at Katherine, Adelaide and Roper Rivers, and Pine Creek.

Danaus hamata hamata Macleay 1826.

Mostly seen in a small rain-forest patch near Darwin, but not abundant. Several observed at Adelaide River and Katherine. Specimens taken in April were mostly worn, but some captured in May appeared to be freshly emerged.

Euploea core corinna (Macleay) 1826.

This is the common *Euploea* of the North, and was noted at Katherine, Adelaide River, Pine Creek, Manton River, Berry Springs and Darwin. The dense shade in forest areas seems to be particularly attractive to this butterfly. Larvae from a small creeper at Elizabeth River, pupated and emerged within a fortnight.

Euploea pelor Doubleday 1847.

Rather scarce and only found in the densely shaded rain-forest at Knight Beach, about four miles from Darwin.

Euploea darchia darchia (Macleay) 1826.

Not common. Mostly observed above the cliffs near the beach at Darwin. Has a leisurely floating flight and is easily caught.

SATYRIDAE.

Melanitis leda bankia (Fabricius) 1775.

First observed at Adelaide River flying at dusk and settling on a cask at the rear of the hotel. Very common at Darwin, where several larvae and many pupae were found in coarse grass. Both the ocellated and plain forms of this variable species were obtained, some of the latter being almost black on the underside. This species was seen at Manton Weir, and at the lily ponds near Pine Creek.

Mycalesis perseus perseus (Fabricius) 1775.

Specimens taken at Elizabeth River and at several localities near Darwin. Keeps to the grass and undergrowth in damp places, usually near running water.

Mycalesis sirius sirius (Fabricius) 1775.

Its habits resemble those of *M. p. perseus;* both species are sometimes found flying in association. Specimens taken are from Darwin, Berry Springs and Adelaide River.

Ypthima arctous (Fabricius) 1775.

Common at Darwin, Berry Springs, Manton River and Pine Creek. It frequents the grass and has a weak flight.

Hypocysta adiante antirius Butler 1868.

This dainty little *Satyrid* is widely distributed and common. Specimens taken are from Adelaide River, Pine Creek, Manton River, Berry Springs and Darwin. Although its flight is weak and it seldom flies far, its habit of flying through the long coarse grass demands patience to secure good specimens.

NYMPHALIDAE.

Hypolimnas bolina nerina (Fabricius) 1775.

Unexpectedly, this well-known butterfly was rather scarce. Most specimens seen during April were much worn, but some fresh examples were secured during the month of May, suggesting the time of our visit was between broods. Captures were made at Darwin, Adelaide River and Katherine. Two pupae were obtained at Katherine on 12 May.

Hypolimnas misippus (Linnaeus) 1764.

More plentiful than the previous species. At Adelaide River both sexes were moderately plentiful in a cucumber patch in a soldier's garden. The owner stated that the butterflies were attacking the cucumbers, but on being questioned, admitted that he had not seen any caterpillars on the vines. A careful search failed to find larvae or pupae. On entering the outdoor bedroom at the hotel at Adelaide River, two pupae were found suspended head downwards, under the window, from which a pair of *H. misippus* emerged. The pupa of this species resembles that of *H. bolina* in shape and has similar sharp dorsal spines, but is smaller and of a uniform brown colour. This species was not uncommon at Darwin. On the wing the female is hard to distinguish from *Danaus c. petilia,* in spite of a different flight.

Cethosia penthesilea paksha Fruhstorfer 1905.

This is another species that closely resembles *Danaus c. petilia* when flying. Two specimens were taken near the cliffs at Darwin, and on only one other occasion was it positively identified when it flew into a dense forest, near Knight Beach.

Precis villida calybe (Godart) 1819.

The commonest butterfly seen in the dry interior. Along the railway line from Quorn to Alice Springs it was identified at frequent intervals. On the Stuart Highway from Alice Springs it was seen as far as Elliott, where examples were collected. On the return journey it was scarce, so that May would seem to be the end of its season in the interior.

Precis orithya albicincta (Butler) 1875.

First observed near Dunmarra, occasionally at Katherine, and commonly at Pine Creek, Adelaide River and Darwin. It was fond of sunning itself on the bitumen roads, but when approached was very alert and actively took flight. The habitat of this and the previous species did not appear to overlap.

Precis hedonia zelima (Fabricius) 1775.

Not common. Observed near Darwin, Berry Springs, Manton River, Elizabeth River, Pine Creek and Lily Ponds, usually near running water. Has a restless flight and keeps to the undergrowth close to streams.

Acraea andromacha (Fabricius) 1775.

Very common and, with its slow flight, easily captured. Recorded from Laramah, Katherine, Pine Creek, Adelaide River, Manton River, Berry Springs and Darwin.

LYCAENIDAE.

Nacaduba ancyra estrella Waterhouse and Lyell 1914. Specimens taken at Adelaide River and Darwin. Very few were seen.

Nacaduba dubiosa dubiosa (Semper) 1878.

This species was also seldom observed. Examples recorded are from Adelaide River and Darwin.

Nacaduba biocellata biocellata (Felder) 1865.

Outside the Gap at Alice Springs this double spotted blue was flying in small numbers and settling on the leaves of a species of *Acacia*. It was not seen further north.

Everes argiades (Pallas) 1771.

Very few seen. Specimens were collected at Adelaide River and Darwin.

Euchrysops cnejus cnidus Waterhouse and Lyell 1914.

Generally observed in all localities visited from Katherine to Darwin. Specimens were collected at Katherine, Adelaide River and Darwin.

Jamides phaseli (Mathew) 1889.

Only seen at Darwin where it was very scarce, and only two specimens were collected.

Catochrysops platissa (Herrich-Schaeffer) 1869.

First observed at Laramah settling on the wet ground at a muddy pool at the railway station. Specimens taken were from Katherine and Darwin.

Anthene emolus affinis (Waterhouse and Turner) 1904.

Rather common at certain spots near Darwin. A fair size colony of larvae and pupae was found on a small sapling near Knight Beach. They were attended by green ants. This species was also recorded from Katherine.

Zizeeria labradus labradus (Godart) 1819.

This notoriously common Blue was in evidence at all localities inspected. Examples were obtained at Alice Springs, Wauchope, Elliott, Adelaide River, and Darwin; those from the drier parts, such as Wauchope, being below the average size.

Zizeeria alsulus alsulus (Herrich-Schaeffer) 1869.

Occurs in most localities north from Katherine. Specimens were collected at Katherine, Dunmarra, Daly Waters, and Darwin.

Zizeeria trochilus putli (Kollar) 1844.

This dainty little Blue frequents the long grass at Darwin but was not often seen, and only two examples were obtained.

Neolucia serpentata (Herrich-Schaeffer) 1869.

Observed flying in a garden at Alice Springs where specimens were obtained. It is a darker race than the species from South Australia. Was not seen north of Alice Springs.

Theclinesthes miskini (Lucas) 1889.

Specimens collected at Katherine and Darwin have been identified as a small race of this species.

Ogyris hewitsoni parsonsi subsp. nov.

Plate I; fig. 7, 8, 9, 10

Male—Above with forewing bright spectrum blue, changing to blue-violet when obliquely viewed; apex and termen narrowly edged with black; cilia smoky grey, almost black at the terminations of the veins. Hindwing bright spectrum blue; costa narrowly black; termen very narrowly black; cilia light grey with black at the veins.

Beneath with forewing brownish-grey; area of cell black with five dull white transverse bars which usually are tinged with blue; a discal dark brown band broken into five irregularly offset sub-rectangular segments, the second being shifted towards apex, and the third towards the base. Hindwing dark grey, lighter towards apex and termen; an irregular wavy pattern of darker grey scales, each pattern margined with black lines.

Female—Above with forewing bright spectrum blue changing to blue-violet when obliquely viewed; white suffusions in cell and in discal area; costa, apex and termen narrowly black; a narrow black bar at end of cell; veins beyond cell faintly black; margin of costa near apex, apex, and termen with small grey patches; cilia grey with black fringe. Hindwing bright spectrum blue; costa and apex black, edged with grey; termen and tornus narrowly black; cilia grey with black fringes.

Beneath with small cell bar at base of forewing orange-brown; a second cell bar narrowly black; a third larger and burnt orange in colour; each bar edged with metallic blue; end of cell with a silver spot, tinged faintly with blue, and surrounded by a broad black area; inner discal area white; discal band black; area beyond discal band to apex with termen light grey, shading darker. Hindwing grey, lighter near costa and apex; in centre of wing a sub-rectangular or zig-zag dark patch; other markings grey, edged with black.

Holotype male, labelled Aileron, Northern Territory of Australia, 5 September 1948, and allotype female, labelled Aileron, Northern Territory, 2 September 1948, collected by F. M. Angel. Both specimens in the collection of the writer; length of forewings respectively 19 mm. and 21 mm.

In addition to the type pair, thirty males and twenty-seven females were bred from larvae taken near Aileron, Northern Territory, on desert oaks (*Casuarina*) on which mistletoe was attached. Five males were captured on the wing on 15 May 1948. The bred specimens emerged at various dates between 5 August and 14 September 1948. All these specimens have been examined.

The type pair selected from the above series are examples of the dominant form. The series as a whole shows considerable variations in markings, particularly on their undersides. In several examples of both sexes the discal band is reduced to two small spots, in areas 2 and 3, and there are other specimens with intermediate stages between this and the dominant form. The general colour scheme on the underside also varies; in two females the conspicuous coloured bar in the cell is dark brown, while one of these is entirely without the discal band; possibly the last named is an aberration.

Another form of variation is in the shade of blue of the upper surface of both sexes. Two different colour types are present; however, the difference between the spectrum blue form and a slightly paler one are so slight that no colour names can be found to differentiate them. Length of forewings, males 16-20 mm., females 18-22 mm.

Ogyris hewitsoni parsonsi may be distinguished from typical *O. h. hewitsoni* by the different shade of blue, and by possessing very narrow black margins to the upper side of the wings. The white suffusion present in the female is characteristic, and the narrow bar at the end of the cell (vestigial in some examples) makes this sex also readily recognisable from typical *O. h. hewitsoni*.

All the specimens taken on the trip have been compared with the long series of species representing *O. amaryllis* and *O. hewitsoni* in the South Australian Museum at Adelaide, as well as those in the collections of F. E. Parsons and the writer. In the South Australian Museum there are two specimens labelled as follows:—

1 male, Konamata, west of Mount Kintore, North-West of South Australia, July 1933, collected by N. B. Tindale.

1 male, Central Mount Stuart, Central Australia, collected by F. Wood Jones.

These are identical with the above specimens and are hereby designated as paratypes. They indicate that the range of this race extends over a considerable area of Central Australia.

The food plant is a greyish species of mistletoe growing on Desert Oak (*Casuarina Decaisneana*). In the daytime, the larvae shelter under loose bark or other suitable cover and are attended by a small species of black ant. In some instances where there was no other suitable shelter, larvae were found in ant tunnels in loose earth. In captivity the larvae were without the ants and their natural food plant, but fed on apple, and a fair proportion were successfully reared.

It may be of interest to record that a specimen of *Ogyris hewitsoni,* probably this race, was observed from the train about twenty miles south of Alice Springs on 18 April, one on the Stuart Highway about fifty miles north of Alice Springs on 20 April, and on 15 May a small number was seen on the wing near Aileron.

The interval of approximately three months or more between these dates, and the emergence of the bred specimens, suggests that this race has at least two broods during the year.

This sub-species is named in honour of Frank E. Parsons, who shared with the writer in the discovery and rearing of this new race.

The paratypes figured on pl. I are examples of the variant markings of the underwings, more particularly in the discal area of both sexes. As mentioned in the description, the dominant form has a continuous though irregular discal band, but this feature is not constant in some specimens and varies in intermediate stages from a well-defined band to two small spots. The upper sides of the specimens figured agree very well with the holotype and allotype, but allowance should be made for the fact the photographic process does not show the white suffusion on the female, which is a distinctive feature of that sex of the subspecies.

Amblypodia centaurus asopus (Waterhouse & Lyell) 1914.

Observed in several localities along the coastal cliffs at Darwin, and also at Parap. It has a strong flight and usually settles high up in trees, but sometimes in low shrubs; in all cases green ants (*Oecophylla smaragdina*) were present near the resting place.

Amblypodia amytis amydon Waterhouse 1942.

Its habits resemble those of the former species, and specimens were obtained in the same localities. In spite of its brilliant colouring on the upper surface of the wings, it is not very conspicuous in flight or at rest. It appeared to be rather more numerous than *A. c. asopus*. A pupa obtained at Elizabeth River, which failed to emerge, was no doubt an *Amblypodia,* although no butterfly of either species was seen there.

Hypolycaena phorbas ingura Tindale 1923.

This butterfly is also associated with the green tree-ant, and is often seen on the same shrubs that *Amblypodia* frequents. The species was rather plentiful in the Darwin area but only occasionally seen inland.

PIERIDAE

Elodina perdita walkeri Butler 1898.

Taken at Darwin flying along the top of the cliffs, also at Berry Springs and Adelaide River. Nowhere was it plentiful or flying in numbers.

Cepora perimale scyllara (Macleay) 1826.

Noticed at Laramah settling on a drying muddy pool on the road. At Adelaide River, Pine Creek, Manton River, Berry Springs and Darwin it was fairly plentiful. Specimens captured showed that they were all of the light phase on the underside, either white or pale yellow.

Anaphaeis java teutonia (Fabricius) 1775.

Odd specimens were observed from the train when nearing Alice Springs. Near the Gap this species was flying in hundreds about a large *Cassia* bush which was stripped almost bare, and on which there were many pupae, and a few larvae struggling for existence. Within fifty yards there were several healthy *Cassia* shrubs which the butterfly apparently had ignored. This species was also found flying in small numbers at Elliott.

Appias paulina ega (Boisduval) 1836.

This species was mostly confined to a small rain-forest near Knight Beach, about four miles from Darwin, where a small number were present. Nearer Darwin it was occasionally seen.

Eurema hecabe phoebus (Butler) 1886.

Specimens were taken at Daly Waters, Katherine, Pine Creek, Adelaide River, Manton River, Elizabeth River, Berry Springs and Darwin. It is the commonest of the grass yellows in the North, and varies considerably in size.

Eurema drona australis (Wallace) 1867.

Recorded from Pine Creek.

Eurema laeta herla (Macleay) 1826.

Several specimens collected at Pine Creek.

Eurema smilax (Donovan) 1805.

Often seen along the Stuart Highway. Specimens were taken at Dunmarra, Pine Creek, Adelaide River and Darwin.

Eurema sana (Butler) 1877.

This species apparently was rare. One specimen was taken at Pine Creek, and another at Adelaide River.

Catopsilia pomona pomona (Fabricius) 1775).

First observed at Elliott, and later at Laramah. At Darwin it was very common along the cliffs, and larvae were found in great numbers; in one instance the foodplant had been completely defoliated. Specimens, both captured and bred, varied considerably in size. Length of forewing varied from 22 mm. to 40 mm.

Catopsilia scylla etesia (Hewitson) 1867.

Although often observed flying with the former species it appeared to be rather scarce. Specimens were taken at the Darwin cliffs, but more often near a rain-forest at Knight Beach.

PAPILIONIDAE.

Papilio fuscus canopus Westwood 1842.

Only a few examples of this swallow-tail were seen, and these in a dense rain-forest near Knight Beach. Specimens captured were all more or less ragged and worn, which seemed to indicate that it was the end of the season for this species.

Papilio demoleus sthenelus Macleay 1826.

One specimen was seen at Wauchope flying over an *Oleander* shrub. At Katherine a small number was seen flying near its foodplant on which one pupa and several half-grown larvae were found. The latter were left for observation on the return journey, but unfortunately a bush fire had destroyed the food plants before the subsequent visit. The butterfly is a strong flyer and very wary. Specimens were collected at Katherine, and one example at Pine Creek. The last mentioned locality is the farthest north the species was noted.

Papilio eurypylus nyctimus Waterhouse and Lyell 1914.

One freshly emerged example was seen hovering over a flowering tree at the edge of the cliffs at Darwin.

Cressida cressida cassandra (Waterhouse and Lyell) 1914.

This species was found rather plentifully at Adelaide River, Berry Springs and other localities near Darwin.

HESPERIIDAE

Neohesperilla croceus (Miskin) 1889.

Two examples taken at Adelaide River on 24th April were the only specimens seen.

Taractrocera dolon diomedes Waterhouse 1933.

Superficially the species of the Subfamily *Hesperiinae* are so much alike when seen in the field, that it is almost impossible to distinguish them with certainty. Particularly is this so with the genera *Taractrocera* and *Ocybadistes,* and as the number of individuals of these two were never plentiful, the species represented in the specimens captured were more than expected. The abovementioned species was represented by a single example taken at Adelaide River.

Taractrocera ina ina Waterhouse 1932.

Several specimens were taken at Darwin on various dates.

Ocybadistes flavovittata vesta Waterhouse 1932.

This species was found in several localities at Darwin, and also at Berry Springs, but at no time were many observed flying together.

Ocybadistes walkeri olivia Waterhouse 1932.

Mostly taken at Berry Springs, where in a small patch near the river they were in fair numbers. Specimens were also collected occasionally at Darwin.

Ocybadistes hypomeloma vaga Waterhouse 1932.

This larger species was rarely seen. Two specimens were obtained at Adelaide River on 24th April, and one at Darwin on 30th April.

Suniana larrakia n. sp. (*vide* description by Mr. L. E. Couchman in addendum).

A specimen taken at Darwin on 28th April 1948 was the only one observed.

Telicota colon argeus (Ploetz) 1883.

Its bright colouring makes this species conspicuous in the field, and it was fairly common at Darwin and Berry Springs. Specimens were also taken at Adelaide River and Katherine.

Telicota augias argilus Waterhouse 1937.

Resembles the previous species in colour and habits, but was not so plentiful. Examples were collected at Berry Springs and Darwin.

Cephrenes trichopepla (Lower) 1908.

Frequently seen in the Darwin area, where its strong flight and showy appearance when it settles attracts attention. It was also noted at Adelaide River.

Borbo impar lavinia (Waterhouse) 1932.

This was scarce. One specimen was taken at Adelaide River on 24 April, and also at Darwin on 28 April and 4 May 1948.

Borbo cinnara (Wallace) 1866.

Specimens were obtained at Adelaide River, Darwin and Berry Springs, where it was more plentiful than the preceding species.

Pelopidas agna dingo Evans 1949.

Recorded from Darwin and Berry Springs during the first week of May, but was only seen occasionally.

Order **LEPIDOPTERA**
Suborder **HETEROCERA**
Family CASTNIIDAE

Plate I; fig. 1, 2, 3, 4

Synemon wulwulam n. sp.

Male—Expanse of wings 39 mm.

Above, with forewing light brown, darker at termen; costa pale cream; a transverse cream area extending from outer part of cell towards tornus to area 2, where it joins with a narrow curved discal band from near the apex; within this lighter area at end of cell an irregular spot dark brown; veins in discal area cream; termen rounded; cilia brown. Hindwing dark brown, almost black, with outer ends of areas 2 and 3 somewhat paler; three or more sub-terminal spots in areas 4, 5, and 6 dull ochreous yellow; termen and cilia with predominantly dark brown scales. Beneath with basal part of forewing from middle of cell to tornus dark brown; outer part of cell to tornus and apex golden yellow; an elongated spot at end of cell dark brown; apex of wing narrowly black; ends of veins from below apex to tornus dark brown obscured with yellow scales; cilia opalescent white with a narrow brown line. Hindwing dark brown almost black; a series of paired spots in areas 2, 3, 5, and 6, and one spot in area 4 golden yellow; cilia with brown and white scales.

Female—Expanse of wings 41 mm.

Above, forewing resembles in markings that of the male, but the colour in the basal half of wing is a somewhat darker brown which accentuates the pattern, and the elongated spot at end of cell is more prominent; cilia with predominantly greyish-white scales. Hindwing very dark brown; areas 2, 3, and 4 have each a single rather brighter ochreous yellow spot near termen, area 5 has two conjoined bright yellow spots, and area 6 a short yellow band formed from two spots; cilia brown with some white scales. Underneath of both wings similar to male.

In both sexes the head, thorax and abdomen are dull brown above and greyish-white beneath. The clubbed antennae are brown above, but underneath the terminal portion of the antennae is greyish-white.

Holotype male, labelled Pine Creek, Northern Territory of Australia, 23 April 1948; and allotype female, labelled Pine Creek, Northern Territory, 11 May 1948, collected by F. M. Angel. Both specimens in the collection of the writer; paratypes are lodged in the South Australian Museum.

The type pair have been selected from a series of twenty-five specimens captured at Pine Creek; it was taken also at Adelaide River, and near Dunmarra. At the last mentioned locality, where the species was first observed, it was flying amongst short undergrowth in a damp spot. A few specimens taken there are larger than the types. At Pine Creek it frequented a dry comparatively bare patch on which the only vegetation was a short stunted species of sedge, which was probably its food plant. The moth was flying in fair numbers on both visits on 23 April and 11 May 1948.

The most striking characteristic of the species is the large golden-yellow patch on the underside of the forewings; the alternate flashing and disappearance of this makes the insect very conspicuous when it is in flight.

Fig. 1. *Synemon wulwulam* n. sp. Holotype male, upperside. Pine Creek, N.T., 23 April 1948.
Fig. 2. Underside of same specimen.
Fig. 3. Allotype female, upperside. Pine Creek, N.T., 11 May 1948.
Fig. 4. Underside of same female specimen.
Fig. 5. *Suniana larrakia* n. sp. Holotype female, upperside. Darwin, N.T., 28 April 1948.
Fig. 6. Underside of same specimen.
Fig. 7. *Ogyris hewitsoni parsonsi* n. sp. Paratype male. Aileron, N.T., 5 September 1948.
Fig. 8. Underside of same male specimen.
Fig. 9. Paratype female, upperside. Aileron, N.T., 14 September 1948.
Fig. 10. Underside of same female specimen.

All figures are approximately natural size.

NOTES ON A COLLECTION OF HESPERIIDAE MADE BY F. M. ANGEL IN THE NORTHERN TERRITORY

BY L. E. COUCHMAN

Summary

Among a number of specimens of the family Hesperiidae recently collected by F. M. Angel in the Northern Territory there are several of considerable interest, notably a new Suniana represented by a single female. In listing these I have adopted the order of genera as given by Evans (1949, Catal. Hesperiidae, Europe, Asia and Australia), an outstanding work that will undoubtedly remain the basis for future work for many years to come.

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L. E. COUCHMAN, F.R.E.S.

Among a number of specimens of the family Hesperiidae recently collected by F. M. Angel in the Northern Territory there are several of considerable interest, notably a new *Suniana* represented by a single female. In listing these I have adopted the order of genera as given by Evans (1949, Catal. Hesperiidae, Europe, Asia and Australia), an outstanding work that will undoubtedly remain the basis for future work for many years to come.

Subfamily TRAPEZITINAE

Neohesperilla croceus (Miskin) 1889. Darwin, N.T.

Although Evans (1949, Intro. p. XII) claims to have retained the original spelling of genera and species, in using *"crocea,"* as elsewhere with *"Pasma tasmanica,"* he has followed Waterhouse and Lyell (1914) in amending Miskin's names.

Subfamily HESPERIINAE

Taractrocera dolon diomedes Waterhouse 1933. Adelaide River,, N.T., 24-4-48. 1 male.

The specimen is very worn, but I have no doubt it is referable to this species.

Taractrocera i. ina Waterhouse 1932. Darwin, N.T., 24-4-48, 30-4-48. Male and female.

Ocybadistes flavovittata vesta Waterhouse 1932. Darwin, N.T., 27-4-48, 8-5-48. Males.

Ocybadistes walkeri olivia Waterhouse 1933. Darwin, N.T., 4-5-48, 5-5-48. Males.

Included here is one unusually small specimen with restricted markings which may prove distinct, but in the absence of more material I place it as a small specimen of this subspecies of *O. walkeri.*

Ocybadistes hypomeloma vaga Waterhouse 1932. Adelaide River, N.T., 24-4-48; Darwin, N.T., 30-4-48. Males.

These specimens have but a faint indication of the distinctive white dorsum on the underside of the hindwings which is characteristic of the type form from Sydney, New South Wales, and do not exactly conform to Waterhouse's description of ssp. *vaga,* but since Waterhouse himself records *O.h. vaga* from Brock's Creek, N.T. (1933, Proc. Linn. Soc. N.S.W., 58 (5/6): 461), I place these specimens here. This is the first record of the species from Darwin.

Suniana larrakia nov. sp.

Plate I; fig. 5, 6

(the native name of the original tribe inhabiting the Darwin district).

Holotype female. Ground colour of forewings and hindwings above mummy brown (Ridgway, Colour Standards and Colour Nomenclature: 15); markings above cadmium yellow (Ridgway 3).

Forewing, cell and costa to vein 9 cadmium yellow, the narrow costal portion of this patch clearly divided by veins 10, 11 and 12. Three small subapical spots, a narrow streak along dorsum and a few scattered scales at base, cadmium yellow. A straight discal band of five spots, from vein 1 at 5 mm. from base towards apex at vein 6, each 1 mm. square, clearly separated by the veins, cadmium yellow.

Hindwing, a few scattered basal scales, a minute spot in area 7, a straight discal band of four rectangular spots, 1·5 mm. by 1 mm., from vein 1 at half towards apex at vein 6, clearly divided by the veins, and a few scattered scales along dorsum, cadmium yellow. Cilia of fore and hindwings brown narrowly tipped cadmium yellow, except at termen of hindwing where the whole width of the cilia is cadmium yellow.

Beneath, forewing mummy brown; cell spot, costal area from base to beyond cell, discal bands and subapical spots as above, with an apical suffusion, cadmium yellow. Cilia brown, tipped cadmium yellow. Hindwing suffused cadmium yellow except for a small spot of ground colour at tornus; the discal band of cadmium yellow spots outlined by the dark veins and by dark crescentic lines. Cilia cadmium yellow. Forewing length 10·5 mm.

Allotype male. Colouration and markings of male as in female, differing only in the slightly deeper tone of the cadmium yellow markings of fore and hindwings above, while the distinct separation of these markings by the veins is not so clearly defined as in the holotype female. Forewing length 10·5 mm.

Holotype female labelled Darwin, N.T., 28-4-48, F. M. Angel, in the collection of F. M. Angel. Allotype male labelled N.W. Australia. K.L. 12038 in the G. A. Waterhouse collection at the Australian Museum, Sydney. Three paratypes, believed to be females, but determination not certain owing to the damaged state of the terminal segments, labelled Groote Eyland, N. Territory, N. B. Tindale and dated Dec. 1921, February 1922 and March 1922, respectively; in the collection of the South Australian Museum, Adelaide.

This is a neat little species, easily distinguished from the other members of the genus (*S. lascivia* Rosenstock and *S. sunias* Felder) found in Australia. From *S. lascivia* it can be distinguished by the uniform width of the discal band of forewing above, and the pale yellow suffusion of the hindwing beneath; from *S. sunias* in both sexes by the uniformly narrow markings of the forewing above, the costal, apical and discal markings being clearly separate, and themselves broken by the darker veins, while the male of *S. larrakia* is without the broad sex brand of *S. sunias* Felder as defined by Waterhouse and Lyell (Butt. of Australia: 204).

Telicota colon argeus (Ploetz) 1883. Darwin, N.T., 30-4-48; 8-5-48. Males Adelaide River, N.T., 24-4-48. Male.

Corbet (1942, Proc. R. Ent. Soc. Lond. (B) 11:92) has shown that the type males of *T. augias* Linn. proves to be conspecific with *T. kreffti* Macleay; the oldest name for any form of the collective species hitherto known as *T. augias* auctt. (nec Linn.) is *T. colon* Fabricius 1775.

Telicota augias argilus Waterhouse 1937. Darwin, N.T., 27-4-48, 7-5-48. Males and 1 female.

Cephrenes trichopepla (Lower) 1908. Darwin, N.T., 30-4148, 9-5-48. Females.

Borbo impar lavinia (Waterhouse) 1932. Darwin, N.T., 4-5-48. 1 male.

Borbo cinnara (Wallace) 1866. Darwin, N.T., 7-5-48. 1 male.

Evans (1949) separates the species of the *B. cinnara* group from *Pelopidas* Walker 1870.

Pelopidas agna dingo Evans 1949. Darwin, N.T., 1-5-48. 1 male.

Rothschild (1915, Novit. Zool., 22, (3): 400) showed that *Parnara mathias* of Waterhouse and Lyell (1914, Butt. of Australia: 212, 35, f. 711, 712, 713) was not true *P. mathias* Fab., but a larger, quite distinct species. Specimens from Queensland in the British Museum were noted as agreeing with examples from Dampier and Vulcan Islands, so Rothschild named this species *Parnara lyelli*. Waterhouse and Lyell's figures of *P. mathias* were given as synonymous, although Rothschild's type male came from Dampier Island.

Evans (1937), Entomologist 70: 65, 66, 81, later showed that true *P. mathias* does not occur in Australia, the specimens hitherto known as *P. mathias* are referable to two species, *P. lyelli* Roths. and the south-eastern race of *P. agna* Moore. Evans placed the Australian form of *P. agna* under s. sp. *parvimacula* Roths., which was based on a male from Dampier Island. Evans (1949) now sinks the name *P. parvimacula* Roths. as a synonym of *Pelopidas mathias repetita* Butler, from New Guinea and the islands and names the form of *P. agna* which flies throughout New Guinea, the satellite islands and North Australia, s. sp. *dingo.*

I can but follow Evans, who has had access to the types in the British Museum. The name *"dingo,"* based on a male from New Guinea, is a most unfortunate choice, since if the Australian form is found to be distinct at some time in the future, the inappropriately named s. sp. *dingo* will be restricted to New Guinea, though perhaps from an Australian view the name will be well lost, considering its common Australian connotation.

Regarding the published figures, some confusion is evident as to the species to which Waterhouse and Lyell's figures 711, 712, 713 should be referred. Rothschild (1915) placed all three figures under *P. lyelli* Roths. Evans (1937), discussing *P. lyelli,* says of these figures, "the male . . . represents a dark form of this species." Waterhouse (1937, Proc. Linn. Soc. N.S.W., 62 (3/4); 119), following Rothschild, refers fig. 711-713 to *P. lyelli,* but Evans (1949) now places fig. 711, 712 under the *agna* s. sp., making no mention of fig. 713, which presumably remains unquestioned *P. lyelli* Roths. The matter can only be settled by reference to the actual specimens from which the figures were taken.

The figures in Waterhouse (1932, What Butterfly is That? 34, f. 10, 10 A) (misquoted by Evans as 11 female, which is *B. impar lavinia*) are unquestioned; pl. 34, f. 10 male is the greenish *P. agna* form, 34, f. 10 A female is *P. lyelli* Roths.

This specimen is the first recorded from Darwin, hitherto the species has only been noted from North Queensland.

I am indebted to my friend F. M. Angel for the opportunity to examine this interesting little collection of Hesperiidae from the Northern Territory, and the Directors of the Australian and South Australian Museums for the loan of material.

ADDITIONAL NEMATODES FROM AUSTRALIAN FISH

BY T. H. JOHNSTON AND P. M. MAWSON

Summary

Parasites from 12 marine host species (including seven elasmobranchs) and 13 freshwater species (most of them from the Lower Murray River, South Australia, are referred to. Accounts are given of Terranova galeocerdonis (Thwaite) from Orectolobus maculatus and Stegostoma tigrinum from Queensland, and Sphyrna lewini from South Australia; larval Contracaecum spp., probably larvae of C. spiculigerum and C. bancrofti, are reported from 13 species of freshwater fish; C. (Thynnascaris) legendrei from Promicrops lanceolatus (Queensland) and Caranx georgianus (South Australia); Acanthocheilus bicuspis from Halaelurus vincenti (South Australia); larval Stomachus sp. (marinus) from additional hosts, Istiompax australis, Trachurus declivis, Sphyrna lewini and Notogaleus australis; Goezia fluviatilis in its larval or adult stage in many species of freshwater fish (Lower Murray River), the larvae often becoming encysted and destroyed in the omentum. Proleptus urolophi n. sp. from Urolophus testaceus differs from other species in its dentition and in the more anterior position of the vulva. Capillaria orectolobi n. sp. is described from Orectolobus devisi. Eustrongylides gadopsis (probably the larva of E. phalacrocoracis from Australian cormorants) is reported from a large number of freshwater fish from New South Wales, South Australia and Western Australia.

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By T. H. Johnston and P. M. Mawson*

[Read 10 August 1950]

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Parasites from 12 marine host species (including seven elasmobranchs) and 13 freshwater species (most of them from the Lower Murray River, South Australia, are referred to. Accounts are given of *Terranova galeocerdonis* (Thwaite) from *Orectolobus maculatus* and *Stegostoma tigrinum* from Queensland, and *Sphyrna lewini* from South Australia; larval *Contracaecum* spp., probably larvae of *C. spiculigerum* and *C. bancrofti*, are reported from 13 species of freshwater fish; *C. (Thynnascaris) legendrei* from *Promicrops lanceolatus* (Queensland) and *Caranx georgianus* (South Australia); *Acanthocheilus bicuspis* from *Halaelurus vincenti* (South Australia); larval *Stomachus* sp. (*marinus*) from additional hosts, *Istiompax australis, Trachurus declivis, Sphyrna lewini* and *Notogaleus australis; Goezia fluviatilis* in its larval or adult stage in many species of freshwater fish (Lower Murray River), the larvae often becoming encysted and destroyed in the omentum. *Proleptus urolophi* n. sp. from *Urolophus testaceus* differs from other species in its dentition and in the more anterior position of the vulva. *Capillaria orectolobi* n. sp. is described from *Orectolobus devisi*. *Eustrongylides gadopsis* (probably the larva of *E. phalacrocoracis* from Australian cormorants) is reported from a large number of freshwater fish from New South Wales, South Australia and Western Australia.

The specimens examined were collected chiefly by the senior author, but we are indebted to Professor J. B. Cleland for some from Encounter Bay; Mr. H. M. Cooper for material from *Caranx* and *Trachurus* from St. Vincent Gulf; Mr. G. G. Jaensch for assistance at Tailem Bend; Dr. A. G. Nicholls and Mr. B. Shipway, C.S.I.R.O. Fisheries Division, for Western Australian material; and Mr. J. S. Lake of Sydney for material from trout in New South Wales.

HOST-PARASITE LIST

Marine Fish

Orectolobus maculatus Bonnaterre. *Terranova galeocerdonis* Thwaite, Caloundra, South Queensland.

Orectolobus devisi Ogilby. *Capillaria orectolobi* n. sp., Port Willunga, S. Aust. This shark is not mentioned by Whitley (1940, 81), but he republished Waite's (1923, 33) figures of it under *O. ornatus halei*, the Gulf Wobbegong.

Stegostoma tigrinum Pennant. *Terranova galeocerdonis* Thwaite, Moreton Bay, South Queensland.

Halaelurus vincenti Zietz (*Juncrus vincenti* in Whitley, 1940). *Acanthocheilus bicuspis* Wedl, St. Vincent Gulf, S. Aust.

Sphyrna lewini Griffith. *Stomachus* sp. larva; *Terranova galeocerdonis* Thwaite, Encounter Bay, S. Aust.

Notogaleus australis Macleay. *Stomachus* sp. larva, Moreton Bay, South Queensland.

Urolophus testaceus Mull. and Henle. *Proleptus urolophi* n. sp., Sydney district, New South Wales.

Promicrops lanceolatus Bloch. *Contracaecum* (*Thynnascaris*) *legendrei* Dollfus, Caloundra, South Queensland.

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* University of Adelaide.

SCIAENA ANTARCTICA Castln. *Contracaecum* (*Thynnascaris*) *legendrei* Dollfus, Caloundra, South Queensland, and Kiama, New South Wales.

ISTIOMPAX AUSTRALIS Whitley. *Stomachus* sp. larva, Mentone, Port Phillip, Victoria.

CARANX GEORGIANUS C. and V. *Contracaecum* (*Thynnascaris*) *legendrei* Dollfus, larva, Outer Harbour, St. Vincent Gulf, South Australia.

TRACHURUS DECLIVIS Jenyns. *Stomachus* sp. larva, Rapid Bay, South Australia.

FRESHWATER FISH

MCCULLOCHELLA MACQUARIENSIS C. and V. *Goezia fluviatilis* J. and M., adult and larva, Murray River, South Australia.

PLECTROPLITES AMBIGUUS Richdsn. *Goezia fluviatilis* J. and M. adult and larva, Murray River, South Australia.

PERCALATES COLONORUM Gunther. *Contracaecum* sp. larva, Murray River, South Australia.

THERAPON BIDYANA Mitchell. *Goezia fluviatilis* J. and M., larva, Murray River, South Australia.

TANDANUS TANDANUS Mitchell. *Goezia fluviatilis* J. and M., larva, Murray River, South Australia.

PSEUDAPHRITIS URVILLII C. and V. *Goezia fluviatilis* J. and M. larva; *Contracaecum* sp., larva; Murray River, South Australia. *Eustrongylides gadopsis* J. and M., larva, Coorong, South Australia. The congolli does not now enter the Murray from the sea because of the barrage near the entrance to the river.

RETROPINNA SEMONI Weber. *Goezia fluviatilis* J. and M., larva; *Contracaecum* sp., larva; Murray River, South Australia.

NANNOPERCA AUSTRALIS Gunther. *Goezia fluviatilis* J. and M., larva; *Contracaecum* sp., larva; Murray River, South Australia.

NANNOPERCA (EDELIA) VITTATA Castln. *Eustrongylides gadopsis*, larva, South-western Australia.

PHILYPNODON GRANDICEPS Krefft. *Goezia fluviatilis* J. and M. larva, Murray River, South Australia.

CARASSIOPS KLUNZINGERI Ogilby. *Goezia fluviatilis* J. and M., larva; *Eustrongylides gadopsis* J. and M., larva; *Contracaecum* sp., larva; Murray River, South Australia.

SALMO TRUTTA *Linn.* *Eustrongylides gadopsis* J. & M., larva, from various localities in New South Wales.

SALMO GAIRDNERI. *Eustrongylides gadopsis* J. & M., larva, Blackwood River, Bridgetown, Western Australia; and from various rivers in New South Wales.

The names applied to the species of trout acclimatized in Australia and New Zealand are confusing. The brown trout has been called *Salmo trutta*, *S. eriox* and *S. fario;* the rainbow trout, *S. irideus*, *S. gairdnerii* and *S. gairdnerii gilberti* (McCulloch, Fishes of New South Wales, 1922, 18-19 ; 1934, 18-19; Mem. Austr. Museum, 5 (1), 1929, 45. Waite, Rec. South Austr. Museum, 2 (1), 1921, 6; The Fishes of South Australia, 1923, 234. Stead, Fishes of Australia, 1906, 33-36. Hobbs, Trout Fisheries of New Zealand, N.Z. Marine Dept., Bull. 9, 1948, 5-6. Also Snyder, The Trouts of California, 1940). Mr. J. S. Lake, Biologist to the Fisheries Branch, New South Wales, in a letter dated 3 August 1950, stated that, until 1946, the river brown and rainbow trout were known as *S. fario* and *S. irideus* respectively; and the sea run types of these two as

S. trutta and *S. gairdnerii* respectively; but that they are now regarded as belonging to *S. trutta* and *S. gairdnerii,* whether sea run or not; and these are the only two species which have become acclimatized in Australia. We have accordingly adopted the specific names accepted by Mr. Lake.

TERRANOVA GALEOCERDONIS (Thwaite)

Fig. 1-4

This species, originally described from *Galeocerdo tigrinum* from Ceylon, has now been recognised from two carpet sharks from Southern Queensland, *Stegostoma tigrinum* from Moreton Bay, and *Orectolobus maculatus* from Caloundra, as well as from the hammer-head shark, *Sphyrna lewini,* from Encounter Bay, South Australia.

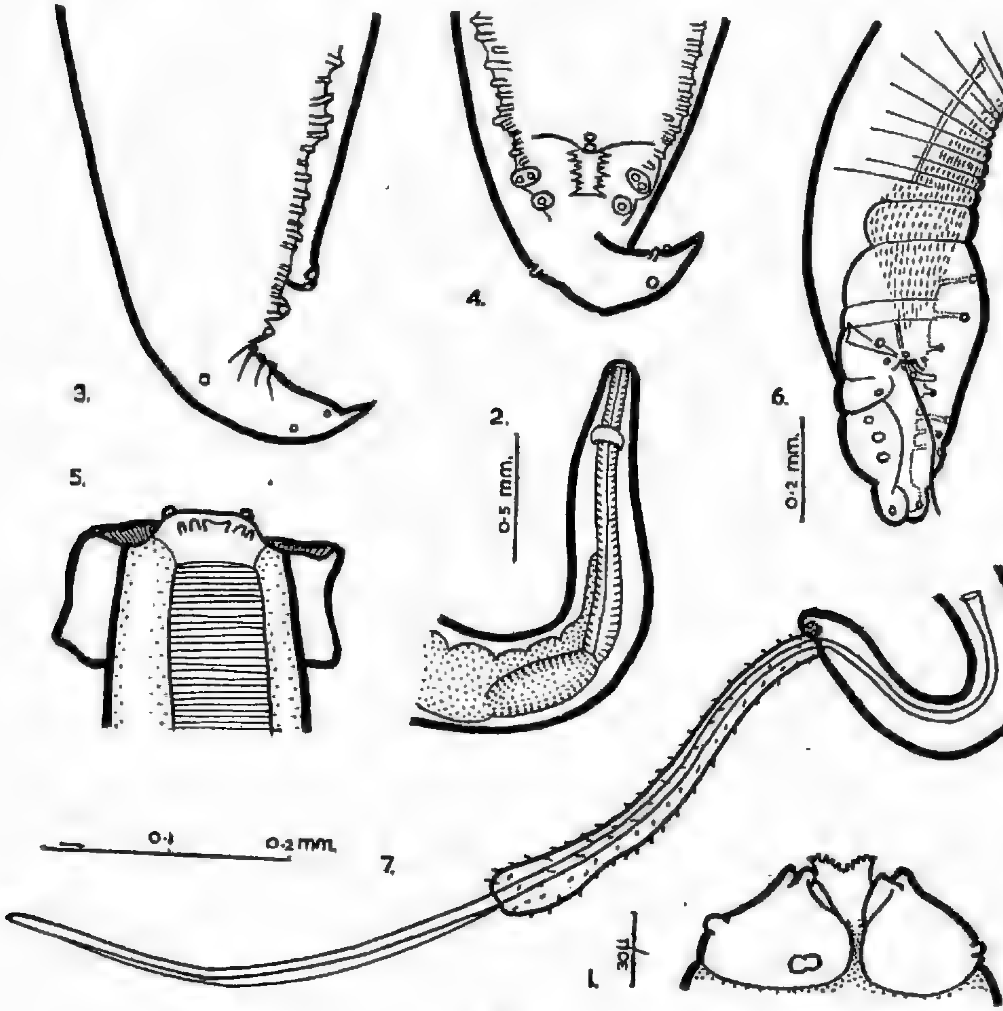

Fig. 1-7

Fig. 1-4, *Terranova galeocerdonis*—1, anterior end; 2, head; 3, lateral, and 4, ventral, views of male tail. Fig. 5-6, *Proleptus urolophi*—5, section through anterior end showing inside of pseudolabium; 6, ventral view of tail of young male. 7, *Capillaria orectolobi,* male tail. Fig. 2, 3, 4 and 6 to same scale (beside fig. 6).

In our material the males are up to 32 mm. in length; the females to 44 mm. The oesophagus is 1:12-14 of the body length, its ventriculus a quarter of the total oesophageal length, and the intestinal caecum about twice the length of the ventriculus. The ratios of these parts are not given by Thwaite, but assuming that the lower figure in each range of measurements given by him refers to the shortest worms, and the higher to the longest worms, the agreement between our specimens and *T. galeocerdonis* is close. The eggs in the Australian specimens are 32-36μ in diameter, not 41μ as recorded by Thwaite. The form of the postanal structure in the male appears to be that of a cuticularised plaque, the lateral edges of which are prolonged into an irregular series of spines. Of the caudal papillae, there are in our specimens two median preanal situated one behind the other in the projecting lip of the anus, and we were able to detect only two pairs, instead of three, close to the tip of the tail. In spite of these differences we consider that our specimens fall within the species *T. galeocerdonis.*

It may be noted that in some larval *Terranova* sp. studied recently by us from an unknown fish host forwarded by the Australian Museum, the proportions of the parts of the alimentary canal resemble those of this species, and it is possible that they represent its larval stage.

CONTRACAECUM spp. (larvae)

Glassy transparent larvae of species of *Contracaecum* s. str., have been found not uncommonly in elongate cysts in the omentum or mesentery of various freshwater fish from the Murray River, between Swan Reach and Tailem Bend. These larvae vary considerably in length due to age. They no doubt belong to *C. spiculigerum* and/or *C. bancrofti* which are common in cormorants and pelicans respectively in the swamps and along the river in the region mentioned. The tail of these larvae is devoid of spines and the oesophagus does not possess a well-defined bulb, thus indicating that it belongs to the subgenus *C.* (*Contracaecum*). The cysts when older tend to become thicker walled and brownish, but they do not usually invest closely the enclosed worms which can move readily within them. We (1947, 551) have already recorded the occurrence of these larvae in *Plectroplites ambiguus, McCullochella macquariensis, Therapon bidyana, Philypnodon grandiceps, Tandanus tandanus, Galaxias olidus, Nannoperca australis, Nematalosa erebi,* and *Mugilogobius galwayi* from the Murray River in the vicinity of Tailem Bend. We now record finding them in *Retropinna semoni, Carassiops klunzingeri, Pseudaphritis urvillii* and *Percalates colonorum* from the lower Murray.

CONTRACAECUM (THYNNASCARIS) LEGENDREI Dollfus

This apparently widespread parasite of marine fish is now recorded as occurring in its adult stage in a Queensland groper, *Promicrops lanceolatus,* from Caloundra, South Queensland, and in *Sciaena antarctica* from Caloundra and also from Kiama, New South Wales. Immature worms were found in *Caranx georgianus* from St. Vincent Gulf, South Australia. We (1945, 133) had previously recorded the presence of the larva from the latter species of fish from Tasmania.

ACANTHOCHEILUS BICUSPIS (Wedl 1855)

This species is recorded from the cat-shark *Halaelurus vincenti,* from St. Vincent Gulf, South Australia. It has previously been recorded by us (1945, 107) as *A. quadridentatus* (Molin) from *Mustelus antarcticus* from various parts of the Australian coast. We follow Punt (1941) in referring the worms to the specific name, *bicuspis* Wedl.

STOMACHUS sp. (MARINUS) larvae

The following species of marine fish are added to the long list of hosts from which *Stomachus* sp. larvae are recorded:—the marlin, *Istiompax australis*, from Mentone, Victoria; *Trachurus declivis*, Rapid Bay, South Australia; the hammerhead shark, *Sphyrna lewini*, from Encounter Bay, South Australia; and the school-shark, *Notogaleus australis*, from Moreton Bay, Queensland.

Dollfus (1948) has drawn attention to the fact that the ventriculus may be either straight or sigmoid in the adult stages of *Stomachus*, for which genus he still retains the name *Anisakis*. His host list refers only to adult stages recorded from Cetaceans and Pinnipedes.

GOEZIA FLUVIATILIS Johnston and Mawson

In our original account (1940, 342) we recorded finding the adult stage of this short plump spiny worm in the digestive tract of *Plectroplites ambiguus*, *McCullochella macquariensis* and *Percalates colonorum* from Tailem Bend; and immature stages in *Nannoperca australis* and *Tandanus tandanus* from Tailem Bend, as well as in *Mogurnda adspersa* from the upper Burnett River, Queensland. Later (1947, 552) we reported it from *Plectroplites ambiguus* from the Thompson River, Central Queensland; and larval stages from *Percalates colonorum, McCullochella macquariensis* and *Tandanus tandanus* from Tailem Bend, South Australia.

Larvae have since been found encysted in the omentum and mesentery of the following additional species of fish in the lower Murray region (South Australia):—*Retropinna semoni; Carassiops klunzingeri; Philypnodon grandiceps; Pseudaphritis urvillii; Therapon bidyana;* and *Plectroplites ambiguus*. It is of interest to note that both larval and adult stages may occur in the same species of percoid fish, *e.g., McCullochella, Percalates* and *Plectroplites*.

The youngest stages seen were found apparently free in the body muscles—perhaps indicating a wandering stage before settling down in their usual habitat in cysts in the omentum. These very small larvae were found in *Carassiops* and *Retropinna*. Another of similar size was found amongst muscle fibres of the teased body of *Philypnodon grandiceps*, but fragments of thin connective tissue were adhering to it, hence it is possible that these tiny worms from the three hosts mentioned may have come from the mesentery or omentum and were in process of becoming encysted. The specimens from *Carassiops* and *Retropinna* were bent dorsally into an open U, while one from *Philypnodon* formed two spirals. The worms from these three hosts measured ·87-·97 mm. long, with a maximum breadth of ·077-·09 mm. The body was widest in the anterior two-thirds, very gradually narrowing towards the anal region, when the tapering became more pronounced. The very short tail was bluntly rounded. The distance between the anus and the tip of the tail was ·055 mm. The lips were well developed, as was the spination on the anterior two-thirds of the body, but the series of spines became very low in the succeeding region, and then practically disappeared, but spines could be seen quite definitely on the ventral surface of the tail. The oesophagus measured 0·158 mm. long (= 1 : 5·5 of body length), its diverticulum (which is relatively extremely long and about three times the oesophageal length) 0·44 mm., and the short intestinal caecum ·03 mm.

The larvae previously described by us were an encysted larva 1·35 mm. long and another 2·8 mm. in length from the omentum of *Nannoperca australis* (Tailem Bend) and *Mogurnda adspersa* (Burnett River, Queensland) respectively.

A degenerating larva from *Tandanus* was coiled within a round, rather flat cyst with its head lying across the rest of the body, the cyst being ·31 mm. in diameter, and closely investing the worm. In another from the same host the cyst was more dense, ·36 mm. in diameter, and the worm more degenerated.

In the Murray cod, *McCullochella*, we have met with many degenerating cysts on various occasions and usually the enclosed worm is no longer recognisable. The *Goezia* worm or its remnant was seen to be more or less straight, curved, partly coiled or irregular; and the inner part of the cyst was very dense when degeneration was more or less complete. Two small round cysts measured ·33 mm. and ·44 mm. in diameter, the outer zone consisting of rather clear fibrous tissue, the denser region enclosing the worm being ·19 by ·16 and ·24 by ·26 mm. respectively. Much smaller cysts were also present but the identification of the causative worm was not possible. In one case the cyst measured ·66 by ·17 mm. and the contained worm ·46 by ·11 mm.; in another cyst ·77 by ·27 mm., the degenerating worm measured ·44 by ·28 mm. In other cases the cyst was much longer and was irregular but the parasite could not be recognised and may have belonged to a quite different species.

Similar degenerating *Goezia* cysts were seen in *Plectroplites, Therapon bidyana* and *Pseudaphritis urvillii.* The last-named fish, the congolli, is anadromous and is not now found in the Murray River since the barrage at its entrance has been completed, the fish now being found in the neighbouring Coorong.

Proleptus urolophi n. sp.

Fig. 5-6

From a stingray, *Urolophus testaceus,* from Port Jackson, New South Wales. Numerous specimens are present. Males up to 9·6 mm. in length; females to 17·5 mm. Cuticular collar more or less pronounced according to age and state of contraction of the worm. Pseudolabia each with two external papillae and five internal teeth of which the median is truncated and the two outer pairs conical. The anterior part of the oesophagus is narrower than the posterior; and is ·33-·4 mm. long in the male, ·4-·5 mm. long in the female, and is surrounded just posterior to the mid-length by the nerve ring. The excretory pore is a transverse cuticularised slit at about the junction of the two parts of the oesophagus. The posterior oesophagus is 1·1-1·3 mm. long in the male, 1·4-1·7 mm. in the female.

Female—Tail an elongate cone, usually dorsally directed. Vulva shortly behind oesophageal region, 2·6-3·4 mm. from head. Eggs 20 by 40μ, with thick shells.

Male—Alae more in the form of bulbous expansions of the cuticle than membranous wings, and not meeting anteriorly or posteriorly. Ventral surface of the precloacal region with longitudinal circular ridges. Three pairs of pedunculate preanal papillae, three median papillae on the anterior lip of the cloaca, four pairs of pedunculate postanal papillae, and almost at the tip of the tail a pair with markedly expanded peduncles. Fig. 6 is of a young male; in older specimens the posterior end is coiled into two or three tight spirals. The shorter spicule is ·18-·2 mm. long, its tip sometimes protected by a membranous "sheath"; the longer spicule is acicular, about ·95 to 1·2 mm. long.

The species appears on general characters of the head and male tail to fall into the genus *Proleptus.* However, the position of the vulva is more forward and the dentition is different from that present in any other species of the genus of which we have seen a description. We have been unable to obtain an account of *P. anabantis* Pearse 1933.

A useful review of the various species attributed to the genus was given by Baylis in 1933. In his description of *P. australis* he states that the host was a "tiger shark" (probably *Galeocerdo tigrinus*) from North Queensland.

Capillaria orectolobi n. sp.

Fig. 7

One whole male and a part of another male worm belonging to the genus *Capillaria* were taken from a carpet shark, *Orectolobus devisi*, from Port Willunga, South Australia. The length of the whole male is 15·3. The cells of the oesophagus are indistinguishable. The oesophageal region, 7·3 mm. long, occupies about half the body length. The alate spicule is 10·1 mm. in length, and its sheath is spinose. The bursa is very small, with one papilla at each side. Bacillary hands appear to be absent from the cuticle.

Eustrongylides gadopsis J. and M.

Additional hosts for the larval stage:—a carp gudgeon, *Carassiops klunzingeri*, from Tailem Bend; congolli, *Pseudaphritis urvillii*, Coorong, South Australia (J. Kimber); western pigmy perch, *Nannoperca (Edelia) vittata*, South-western Australia (B. Shipway); brown trout, *Salmo trutta*, New South Wales rivers; rainbow trout, *S. gairdneri*, Blackwood River, Bridgetown, Western Australia (Dr. A. G. Nicholls); also from the New England area, Macdonald River, Major's Creek (Central Western New South Wales), Sodwalls Creek, Little or Retreat River, Monaro district (especially the headwaters of the Lachlan River), all of these localities being in New South Wales (J. S. Lake). Other Australian fish hosts for the larva have already been recorded by us (1940, 350; 1944, 64; 1047, 548).

The presence of the adult stage, described by us as *E. phalocrocoracis*, in cormorants in New South Wales and Western Australia may be inferred.

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GEOLOGY OF THE PIDINGA AREA

BY D. KING

Summary

A complete succession of marginal sediments of the Nullarbor Plains Basin which occur in and adjacent to the Pidinga Lakes were carefully mapped and sampled, and Part I deals with the geological findings. The lower beds are of lacustrine origin and include lignitic and alunitic clays. These are overlain by Middle Miocene marine limestone. Siliceous and ferruginous laterites, forming a capping in some areas, are believed to have developed in Pliocene times.

GEOLOGY OF THE PIDINGA AREA (1)

By D. King*

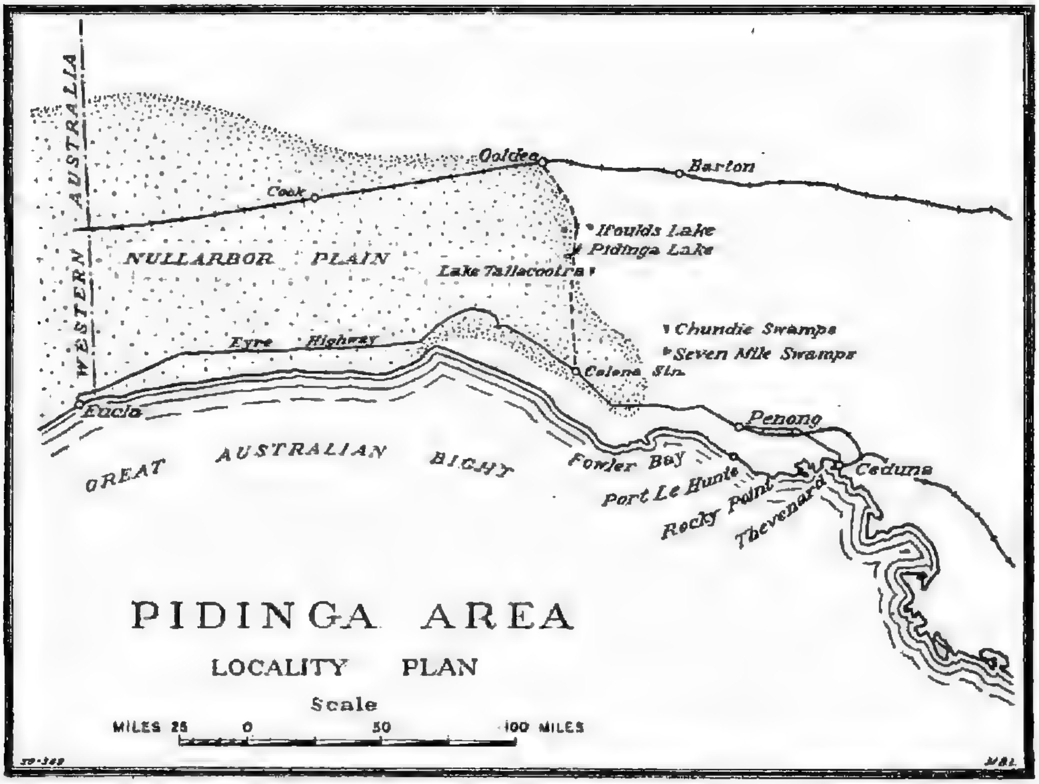
[Read 10 August 1950]

SUMMARY

A complete succession of marginal sediments of the Nullarbor Plains Basin which occur in and adjacent to the Pidinga Lakes were carefully mapped and sampled, and Part I deals with the geological findings. The lower beds are of lacustrine origin and include lignitic and alunitic clays. These are overlain by Middle Miocene marine limestone. Siliceous and ferruginous laterites, forming a capping in some areas, are believed to have developed in Pliocene times.

Precambrian gneisses also outcrop over a large area in the vicinity of Pidinga. Part II is a detailed petrological study of the gneisses.

The geological plan of the Pidinga area was constructed by compass and chain traverses, and is accurate to within the limits permitted by this method. The plan shows only actual rock outcrops or geological data obtained from bores and test pits.



PREVIOUS REFERENCES

The geology of this region has received very little attention in the past due to the lack of transport facilities and water supplies, and the great distances between rock exposures.

(1) Portion of a thesis submitted for the Degree of Master of Science at the University of Adelaide.

*Assistant Geologist, Department of Mines.

Brief references to the physiography and prevailing rock types of the area appear in the published accounts of early South Australian explorations, among which the reports of Tate (1878), Jones (1880), Giles (1889) and Brown (1885 and 1898) are the most notable. Specialised investigations of shallow lignite and a recently discovered alunite occurrence at Pidinga are referred to in the publications of the South Australian Department of Mines.

PHYSIOGRAPHY

Pidinga is situated 39 miles south of Ooldea, a siding on the trans-continental railway, in the far western portion of South Australia. At Pidinga there is a series of dry saline lagoons situated in a broad depression forming the eastern boundary of the vast Nullarbor Plain. Broadly speaking, the eastern margin of the plain comprises a series of such shallow depressions with chains of lakes. The lakes generally contain outcrops of Precambrian and/or Tertiary rocks which are elsewhere in this region obscured by a thin mantle of soil or drift sand.

The Main Pidinga Lake is elongated in a N.E.-S.W. direction, measuring 14 miles in length and with an average width of one quarter of a mile, parallel to a ridge of bare hills on the western flank. These rise about 100 feet above the level of the lake and 30-50 feet above the adjacent Nullarbor Plain. A typical panorama across portion of the lake is shown in pl. II, fig. 3. The ridge is much dissected on the eastern side, with numerous creeks draining easterly into the lake, the edge of which is often sharply defined by low cliffs. The western flank of the ridge smooths out gradually and merges into the Nullarbor Plain. The ridge comprises gneissic Precambrian rocks.

The greater part of the eastern margin of the lake is defined by sandhills or flour gypsum dunes, beyond which is broadly undulating country with a travertinous soil and thick herbage of myall, mulga, sandalwood and quondong. There is very little surface drainage into the lake on its eastern margin.

The Main Pidinga Lake, and other small lakes in the vicinity, which are linked to one another by partly drifted and vegetated depressions, have an ill-defined drainage in a southerly direction. The lake narrows out in the south-western portion to a mere watercourse about 50 yards wide, covered with a silty soil and thickly timbered with mallee, ti-tree and myall. This watercourse ends abruptly in an extensive timbered flat surrounded by limestone cliffs about 12 feet high (plate II, fig. 4), beyond which is the Nullarbor Plain proper.

It is considered likely that the ancient watercourse recognised at Pidinga was very active during the high rainfall conditions of the Pleistocene period responsible for the excavation by solution of the extensive caverns of the Nullarbor Plain limestones (King, 1949). Moreover, as the Main Pidinga Lake ends suddenly in a large depression resembling a sink-hole, surrounded on three sides by the Nullarbor Plain, present day floodwaters following exceptional rain, in all probability, still continue to pass underground into the porous chalky limestone below the plain at this point. In other words, this southern extremity of the Pidinga Lake is still an intake source for the ground water of the Nullarbor Plains Basin.

PART I—THE TERTIARY SEDIMENTS

During early Tertiary time, shallow freshwater sediments, including lignites, were deposited in surface depressions in the Precambrian shield. The area to the west of Pidinga, now defined by the Nullarbor Plain, was a notable depression in which the lacustrine conditions were followed by an invasion of the

sea, resulting in the deposition of a thick bed of polyzoal limestone. Marine conditions prevailed until the Middle Miocene, when a shallow sea covered the Pidinga area. The Tertiary sediments at Pidinga, both fresh-water and marine, show considerable variations laterally as would be expected under shallow water conditions. The general stratigraphic succession of the beds, which are normally horizontal, is shown in Diagram No. 3.

The Oligocene [2] *Lignitic Series — Lacustrine*

The earliest reference to the occurrence of lignite at Pidinga was made by the former Government Geologist, H.Y.L. Brown, in the year 1885. Brown reported that a trial bore had been sunk into the lake by a Mr. Ifould, with the following results: 0-30 lignite: 30-39 grey clay and ironstone: 39-40 lignite. The approximate location of the bore is shown on the geological map (Plan No. 2).

Further recent exploratory work on the lake has revealed that an area of approximately one square mile is underlain at shallow depth by a bed of low-grade lignite, ligneous sand and clay. Actual brown coal was found within three feet of the surface. A borehole (No. P15) sunk by the Department of Mines in 1948 to test the thickness of the coal and obtain reliable samples for analytical purposes penetrated 45 feet of carbonaceous material above grey clay. The bore was not continued to bedrock. Analyses of various horizons disclosed that even the most promising of the lignite was very high in ash. Irregular masses of pyrites intergrown with lignite were observed in the lignitic sand between 36½ and 41½ feet. Another constituent of the lignite is fossil resin. Samples from this borehole were sent to the C.S.I.R.O. Pollen Research Laboratory at the Melbourne University and the following observations were made by Miss K. M. Pike, B.Sc. (1949).

"The clay shows a rich assemblage of pollen and spores, representing the families: — *Proteaceae, Myrtaceae, Epacridaceae, Fagaceae,* together with other Gymnosperms, and fern spores. A comparison made with preparations from Moorlands brown coal revealed that many of the pollen and spore types were present in both coals, except that *Myrtaceae* appear to be absent from the Moorlands coal. There is thus a suggestion that the Pidinga deposit might be of the same general age as Moorlands."

The early Tertiary age of the beds thus indicated by pollen and spore determinations is supported by stratigraphic considerations. The following section was obtained by sinking a trial auger hole (Section No. 1 on the geological plan) at the foot of the cliffs in an embayment on the western edge of the lake.

	feet	
Cliff	0 – 3	fossiliferous silicified limestone.
	3 – 4	off-white gypseous and gritty clay — large selenite crystals.
	4 – 9	vari-coloured ferruginous clay; some ironstone nodules.
	9 – 10	red ochreous sand.
Auger hole	10 – 11	red ochreous sand.
	11 – 11½	yellow and white mottled clay.
	11½ – 13	yellow ochreous sand.
	13 – 17	vari-coloured iron-stained sandy clay.
	17 – 19½	yellow ochreous sandy clay.
	19½ – 20	lignitic clay and sand.

[2] The Early Tertiary lignites which occur below the marine Miocene beds throughout a large area of southern Australia are generally referred to as of Oligocene age. Miss Crespin (1945) considers they are Lower Miocene.

The limestone at the top of this succession contains fossils typical of the South Australian Middle Miocene.

At another locality (Section No. 2) the lignitic bed underlies cliffs capped with porcellanite.

	feet	
Cliff	0 – 3	porcellanitic grit and surface quartzite.
	3 – 5	pale coloured sandy clay — mainly white.
Auger hole	5 – 8½	pale vari-coloured sandy clay — mostly yellow.
	8½ – 9½	carbonaceous clay with fragments of decomposed wood.

The lignite can be correlated in age and mode of occurrence with that of Lake Tallacootra, and with another deposit discovered by the writer at Seven Mile Swamps, about 60 miles south-east of Pidinga, in the north-western portion of County Kintore. In each of these cases, lignitic clay occurs under similar circumstances, namely, below the beds of lake depressions of Middle Miocene limestone. Probably the lignitic clays reported during the coarse of boring for water at Malbooma (Ward, 1939), situated about 120 miles north of east from Pidinga, and in a bore sunk by the Commonwealth Railways east of Ooldea, are also of comparable age.

Lower Miocene Shallow Water Sediments — chiefly Lacustrine

These include the unconsolidated beds of soft clay, sand and grit, in part ferruginous, which occur at and below the surface over large areas in the Pidinga lakes, and are in many places exposed in the lower levels of the cliffs fringing the lakes. The sediments are typically a shallow-water suite. The lower beds are completely unfossiliferous but minute marine organisms have been found to occur in the uppermost horizons. They are tentatively assumed to be of Lower Miocene age as they overly Oligocene lignite and are capped with Middle Miocene marine limestone. Their deposition, therefore, was probably contemporaneous, with the polyzoal limestone formation of the Nullarbor Basin which occurs between the same beds. The porcellanites which in some places form a capping to the clays, etc., are regarded as part of the same formation but they are treated in more detail under a separate heading, as processes of a later geological period were apparently responsible for their alteration to a hard dense silicified state. In several localities the beds show pronounced dips which are possibly due to minor faulting or warping.

A unique but ideal locality for the study of the stratigraphic succession in these sediments is a small outlier capped by fossiliferous limestone in the centre of the Main Pidinga Lake (see pl. II, fig. 1). It forms a prominent landmark and the reason for the preservation of this "island" of unconsolidated sediments, elsewhere eroded to form the Pidinga Lake, is probably the limestone capping having been particularly resistant to erosion. It serves a very useful purpose in showing a complete succession of strata from the Oligocene lignitic beds underlying the Pidinga Lake surface to the Middle Miocene fossiliferous limestone. A trial hole was sunk at the base of the knoll, and on the assumption that there is no faulting, it was found that about 20 feet of the Lower Miocene sediments overlie the lignitic beds. The succession (Section No. 3) is as follows:

	feet	
Cliff	0 – 4	fossiliferous limestone — gritty
	4 – 6	yellow and green angular sand and grit
	6 – 8	white and friable gypseous clay
	8 – 14	white and grey clay with patches of iron oxide stains

Auger hole	14 – 15	fine pale yellow ochreous sand
	15 – 17	fine pale yellow ochreous sand — patches of white sandy clay
	17 – 19½	fine red ochreous clayey sand
	19½ – 20	red gritty ferruginous clay
	20 – 22	grey clay, slightly gritty — some mica flakes
	22 – 23	fine white and pale yellow sand
	23 – 23½	bright yellow ochreous fine sand — some mica
	23½ – 24½	grey and purple sandy clay
	24½ – 25	brown carbonaceous sandy clay — some iron-stained patches
	25 – 25½	red and purple ferruginous sand and grit
	25½ – 29	grey and brown carbonaceous clay and sand.

The bed of angular sand and grit directly below the limestone in this section was observed in several other exposures on the western edge of the Main Pidinga Lake, where it contained numerous platy crystals of selenite.

Generally speaking, these sediments become increasingly sandy towards their base and, as in the section quoted, beds of very fine quartz sand stained with ochre separate clay beds from the underlying lignitic beds. In other areas, the ochreous sands are absent and the Lower Miocene sediments consist almost exclusively of white and vari-coloured clays. The contact with the lignitic series is sometimes sharp, but in borehole P15, on the Main Pidinga Lake, and in other bores on Lake C, the change is gradational with white clay interbedded with lignite. The contact of the Oligocene and Lower Miocene sediments cannot be accurately placed in the bore on account of the overlapping of conditions of deposition of the respective sedimentary formations. The uppermost appearance of the carbonaceous material is taken as the top of the Oligocene and this is really the only distinguishing characteristic from the overlying beds.

Another feature of the Early Miocene lacustrine sediments is that they are lenticular, as if they were laid down on an uneven surface, perhaps shrunken remnants of the original extensive lake in which the lignite accumulated. Whilst the series is generally unfossiliferous the uppermost bed has indications of a marine radiolarian (genus *Cenosphaera*) determined by Miss I. Crespin. Although Miss Crespin suggests from a laboratory study (*Rock No. 146*) that the radiolarian may be a Cretaceous form, the field evidence cannot in any way support this conclusion as these particular beds are definitely underlain by Oligocene lignite and overlain by Middle Miocene limestone, both fossiliferous. The presence of a marine fossil in the uppermost bed probably represents the beginning of the marine incursion which resulted in the deposition of the Middle Miocene limestone.

It may be noted here that a feature of these sediments is their alunitic character. In some localities they contain such a high proportion of available potash as to be classed as a commercial alunite. This property is regarded as having been acquired and not of syngenetic origin. In their original state, the clays probably represent a normal accumulation of kaolinitic decomposition products from the weathering of the feldspathic gneiss rocks.

Apart from the disseminated ochreous stains which characterise this formation as a whole, there are commonly developed, within the upper horizons of the clay, nodules or discontinuous flat beds of a ferruginous siliceous nature. That these are of secondary origin and caused by similar alteration processes, namely lateritization, as those responsible for the induration of the porcellanites and surface quartzites discussed later, is indicated by the study of a

thin-section. *Rock No. 138* is a very fine-grained red-brown, siliceous rock. The section consists of a fine even-grained meshwork of quartz in which individuals are clear hexagon-shaped crystals of secondary origin, and with vari-coloured iron oxide as the cement.

Middle Miocene Fossiliferous Marine Limestone.

Isolated outcrops of coarse crystalline limestone occur at numerous points along the western margin of the Pidinga Lake. Typical successions capped with limestone have already been quoted (Sections Nos. 1 and 3), and the latter is reproduced in pl. II, fig. 1. The bed is only a few feet in thickness and in general forms a capping over the Lower Miocene sands and clays previously described, or decomposed bedrock gneisses. The limestone is highly silicified and commonly stained with yellow and brown tinges of iron oxide. An abundance of rounded quartzose pebbles and grit within the matrix of the limestone, and the unusually large size of many of the included fossils, are indicative of littoral conditions, as would be expected in the neighbourhood of the protruding older rocks.

In the more westerly of the lakes, and at the south-western extremity of the Main Pidinga Lake, the limestone is of greater thickness and the underlying beds are not exposed. West of the eroded area, the limestone occurs again beneath a mantle of soil and travertine rubble, as part of the upper "hard crust" of the Nullarbor Plain. On the north-eastern edge of the lake, and beyond, the underlying rocks are obscured by a coverage of sand and loam and there are no limestone outcrops, but when due consideration is given to the relative levels, it is suspected that the shallow sea did extend much further east than Pidinga.

The limestone is notably rich in fossil casts of large shells. Notable fossils are *Marginopora vertebralis* and *Notovola subfossilis.* Thin-sections of the limestone were studied by Miss I. Crespin (Report No. 1949/93). The assemblage of micro-fossils was found to be almost identical with that in samples of the surface rocks from the Nullarbor Plain (King, 1949). Micro-palaeontological descriptions of individual samples are as follow:—

Rock No. 19. A hard silicified foraminiferal limestone.

Plantae—*Lithothamnium ramosissimum.*

Foraminifera—*Marginopora vertebralis; Quinqueloculina* sp. *Triloculina tricarinata; Valvulina* cf. *fusca;* Small *miliolidae* indeterminate.

Rock No. 115. A hard silicified foraminiferal limestone.

Foraminifera—*Austrotrillina howchini; Bolivinella* cf. *folia; Cibicides refulgens; Elphidium* cf. *adelaidensis; Marginopora vertebralis; Planorbulina mediterranensis; Rotalia* cf. *calcar; Triloculina tricarinata;* small *miliolidae;* small *rotalines.*

Rock No. 135. A coarse shelly sandstone with broken tests of foraminifera, including *Marginopora vertebralis.*

In a summary, Miss Crespin writes:—

"*Rock No. 135* is a shelly sandstone containing *Marginopora vertebralis.* The rock is regarded as Lower Pliocene in age and as an equivalent of the fossiliferous beds at Hallett's Cove, south of Adelaide, and of the 'Adelaidean' deposits which underlie the Adelaide Plains.

Rocks Nos. 19 and 115 represent the Middle Miocene limestone which is typical of many outcrops west of Adelaide, especially on the Nullarbor Plains. *Austrotrillina howchini* is common in *Rock No. 115* where it is associated with *Marginopora vertebralis.* Although *Austrotrillina howchini*

is not present in the two small sections of No. 19 sent for examination, the lithology and mode of preservation of the foraminifera suggest if further sections were available this form would be found."

In view of the relatively small thickness and homogeneity of the formation, and the presence of the Middle Miocene index fossil *Austrotrillina howchini*, it may best be regarded as entirely of Middle Miocene age.

Derivation of the Porcellanites or Siliceous Laterites.

The crust of dense porcellanite which forms a capping to a number of the outcrops of soft clay and sand, etc., was probably formed under similar climatic conditions to that which produced the siliceous laterites covering the surface of large areas of the Australian Tertiary peneplain. These have been regarded as fossil soils due to leaching and chemical redistribution of mineral matter in solution during a period, or periods, of humid and high rainfall conditions, and are generally referred to as the "Duri-crust."

The sediments which have been silicified at Pidinga are no exception to this condition of formation and originally comprised clay, sand or grits from the upper horizons of the Lower Miocene shallow-water sediments. In other places in the vicinity of the lakes the same beds, but not indurated, are overlain by Middle Miocene marine limestone. A section exposed in a cliff on the western edge of Lake C (Section No. 4 on the geological plan) is typical of those in which porcellanite is present.

feet	
0 – 4	white porcellanised claystone, heavily iron-stained.
4 – 9	white sandy alunitic clay — soft.
9 – 11	yellow ochreous sandstone.
11 plus	white gritty alunitic clay.

A thin-section of a specimen from this outcrop (146) confirms that the porcellanite was derived by silicification of gritty clay similar to that which it overlies, as the texture of the rock is pseudomorphous after clay. The specimen is a dense white porcellanite with a splintery fracture. Small grains of quartz are visible to the naked eye. Under the microscope, the rock consists of a pale brown siliceous matte which has no reaction to polarised light. Occasional grains of detrital quartz present have rounded outlines and show undulose extinction. Included grains of un-twinned plagioclase, typical of the Precambrian rocks, are also present in small quantities.

Although the sediments which have been silicified are Early Miocene in age, it is considered that the lateritisation occurred in Upper Miocene or Pliocene times, and the following observations were noted in support of this conclusion:

1. A silicified crust is developed at Pidinga only in the areas where the limestone has been completely denuded by erosion. (An exception does occur at Ifould's Lake, four miles north-west of Pidinga, where grey clay and partially porcellanised grit underlies a very thin bed of fossiliferous limestone).
2. No fragments of porcellanite were observed within the pebbly fossiliferous limestone, either by the naked eye or in thin-sections. The pebbles consist only of detritus from the Precambrian rocks.
3. The fossiliferous limestone is itself highly silicified.
4. The "Duri-Crust" was formed prior to the excavation of the Pidinga lake systems (Pleistocene), as large boulders of the formation occasionally litter their surface.

It is likely, therefore, that the processes responsible took place during the Pliocene period. This is in agreement with findings in other parts of Australia, for example, Whitehouse (1940) and Crocker (1946) reached a similar conclusion following studies in Queensland and South Australia respectively.

DIAGRAM

SHOWING

THE GENERAL STRATIGRAPHIC SUCCESSION AT PIDINGA

MAXIMUM OBSERVED THICKNESS	SECTION	DESCRIPTION OF STRATA	PALAEONTOLOGICAL DATA	AGE AND ENVIRONMENT
4'-0"		*Flour gypsum & seed gypsum - Wind blown.*		RECENT *Terrestrial*
12'-0"		*Fossiliferous silicified limestone - abundant quartz grit.*	*Foraminifera: Austrotrillina howchini Marginopora vertebralis, etc. (Crespin)*	MIDDLE MIOCENE *Shallow Marine*
4'-0"		*Porcellanised claystone and grit, surface quartzite etc.*	*Radiolaria: Cenosphaera (Crespin)*	
3'-0"		*Pale yellow and green gypseous quartz sand and grit*		
5'-0"		*White friable gypseous clay - some selenite crystals*		
4'-0"		*Pale grey sandy clay patches of ironstone and ferruginous sandstone*		
28'-0"		*White and vari coloured alunitic clay*	*Lower beds are unfossiliferous*	LOWER MIOCENE *Mainly shallow lacustrine*
7'-0"		*Red, brown and yellow fine ochreous sand or ochreous sandstone crust.*		
2'-6"		*Yellow, red and grey mottled clay - sandy.*		
6'-6"		*Vari-coloured iron-stained mottled clay*		
3'-0"		*Yellow grey and brown clay, some gypsum crystals.*		
2'-0"		*Carbonaceous sandy clay stained with iron oxide.*		
46'-0"		*Lignitic Series* *Carbonaceous clay and sand with fragments of decomposed wood and pyrites.*	*Pollen & Spores of families: Proteaceae Myrtaceae Epacridaceae Fagaceae (Pike)*	OLIGOCENE *Lacustrine*
1'-0"+		*Grey clay with some carbonaceous material*		
15'-0"		*White and iron-stained gritty alunitic clay with the texture of decomposed gneiss.*		DECOMPOSED PRE-CAMBRIAN
MSL		*Gneissic granite, epi-diorite and amphibolite etc.*		PRE-CAMBRIAN *Metamorphic*

Fig. 3

PART II — PETROGRAPHY OF THE PRECAMBRIAN ROCKS

A detailed petrological study of the Precambrian gneisses which are exposed in the vicinity of the Pidinga Lakes is presented in this section, and reference is also made to similar occurrences at Ifould's Lake and Lake Tallacootra. Previous work has amounted to brief general descriptions of the gneisses by the former Government Geologist, H. Y. L. Brown (1898) and explorer F. R. George (1905).

GENERAL CHARACTERS AND CONSTITUTION

The belt of gneisses which outcrops at Pidinga is the largest exposure of the Precambrian formation in South Australia west of the Gawler Ranges and south of the Trans-continental Railway, and with the smaller occurrences at Ifould's Lake and Lake Tallacootra, are the most westerly in South Australia south of the railway line.

The Precambrian rocks protrude at intervals for a distance of approximately eight miles along a ridge on the western fringe of the Pidinga Lakes, and at some places on the lakes (pl. III, fig. 1). They consist of an assortment of gneisses in which the components are transgressional from one to the other or intermingled in a complex fashion, features which are common to many of the other occurrences of Precambrian rock in western South Australia. They are considered tentatively as Archean in age and may be correlated with the similar formations of south-eastern Eyre Peninsula and lower Yorke Peninsula which are overlain unconformably by Proterozoic sediments.

The gneisses which occur at Pidinga may be classified into three major groups:—

1. *Older Series of Gneisses*—The older gneisses are mainly dioritic in composition but also there are highly metamorphosed calcareous and siliceous sediments, amphibolites and plagioclase hornblende schists, occurring as irregular intercalations within the dioritic gneisses. A characteristic of this group of rocks is the presence of abundant dyke-like intrusions and segregations of pegmatitic and aplitic appearance and composition.

2. *Basic Rocks*—Included here are metamorphosed basaltic dyke rocks and an occurrence of peridotite, all of which intersect the older series of gneisses.

3. *Granitic Augen-Gneisses and Associated Migmatites*—This group comprises uniform granitic rocks and related migmatites of younger origin.

The variety of gneisses recognised have in the majority of cases such complex inter-relations that it is not possible to map them as separate identities. The difficulties of interpretation are increased by the discontinuity of outcrops which has resulted from preferential erosion. The ridge of Precambrian rock probably owes its prominence to the resistance to weathering of the granitic members which recur as bold outcrops at intervals throughout the area. The other types are exposed only where creeks have dissected deeply into the sedimentary coverage, or as erosion platforms at the surface of the lakes.

The general foliation of the gneisses is reasonably uniform at each of the outcrops. The strike ranges from 10° E. of N., to 50° E. of N., and the dip is almost always vertical. Local exceptions are mentioned in the text.

As the outcrops are geographically intermediate between the gold-bearing Precambrian rocks of Tarcoola (South Australia) and Kalgoorlie (Western Australia), the area has been thoroughly prospected, but no metalliferous minerals in any appreciable quantity have ever been reported. A suite of samples from Pidinga were assayed for gold by the Mines Department (1933). None were found to be auriferous. Graphite occurs disseminated throughout the gneisses on the western edge of Ifould's Lake, but in such small quantity as to be of only academic interest.

A number of specimens representative of the formation as a whole were submitted to the Geophysical Section of the Mines Department for determination of radioactivity. The results were "not significant."

THE OLDER SERIES OF GNEISSES

Intercalated Sedimentary Gneisses

There is evidence that portion of the gneissic terrain originally comprised rocks of sedimentary character, which were later almost completely digested by igneous intrusions, or otherwise highly altered by metamorphic and additive processes.

At Pidinga, there are incorporated in the gneisses on rare occasions some small remnants of fine-grained highly siliceous rocks resembling quartzite, and calc-silicate types. These occurrences are characterised by pseudo-bedding structures in which the dips are much flatter than the vertical foliation of the igneous gneisses.

The occurrence of graphite as a disseminated mineral throughout the gneisses exposed on the western fringe of Ifould's Lake, four miles north-west of Pidinga, and the abundance of cordierite in other specimens, are other features which, although not real criteria, are characteristic of gneisses of sedimentary origin.

Typical of the calc-silicates is a pale greenish-grey fine-grained *scapolitised clinozoisite diopside grossularite rock* (52). Free calcite also occurs in abundance, and the minor constituents are zoisite, epidote, sphene, plagioclase, quartz and magnetite. The minerals are irregularly distributed and the micro-structure is granoblastic. The assemblage is characteristic of a regionally metamorphosed magnesian limestone.

A coarse variety of calc-silicate, a *garnet epidote calcite rock* (33), occurs as what is apparently a xenolith in dioritic gneisses. It is a handsome rock consisting of shapely crystals of reddish garnet and green epidote associated with pink calcite and some quartz, and varying in grain size from medium to very coarse. The rock comprises the dump around a small pit situated about one-quarter mile east of Pidinga Rockhole. The epidote was previously designated green tourmaline by explorer F. R. George (1905), who discovered and prospected this interesting occurrence. There are no outcrops in the immediate vicinity of the pit, but close at hand in all directions the country rock consists of dioritic gneiss. An unusual and quite porous calcareous capping is the only surface indication of the occurrence. The pit has fallen in and the specimens lying at grass consist only of this rock.

Cordierite-bearing rocks are known only from a small exposure at the eastern end of Ifould's Lake (102), which consists of fine to medium-grained *feldspar garnet cordierite gneiss*. Grey bands rich in feldspar and quartz alternate with dark bands composed of biotite, garnet and yellow cordierite. The mineral composition is typical of gneisses derived from argillaceous sediments with their high alumina content.

In thin-section, there is a pronounced foliation of the mineral constituents and the texture is for the most part granoblastic, with a modification in some places where shear has effected granulation at the margins of the grains. The chief minerals present are microcline microperthite, cordierite, plagioclase, quartz, biotite and garnet. Clinozoisite and rutile are conspicuous accessory components. Also present in small quantities are muscovite, titaniferous iron ore, zircon and epidote. Another specimen from the same locality (99) is very similar apart from a higher proportion of potash feldspar relative to plagioclase.

Amphibolites and Plagioclase Hornblende Schists

Amphibolites and plagioclase hornblende schists occur as abundant discontinuous masses and schlieren within the complex of older gneisses. A typical

area is shown in pl. III, fig. 3. They resemble in every detail the larger amphibolitic masses observed as inclusions in the gneisses elsewhere in western South Australia, as for example those of Rocky Point and Cape Thevenard (near Penong and Ceduna, respectively). In each of these places the amphibolite appears to represent remnants of former basic igneous (doleritic?) bodies, emplaced as sills or dykes, or perhaps surface flows, prior to the regional metamorphism and related processes which were responsible for their partial obliteration and alteration. It seems likely that they are all related to one and the same period of basic intrusion, or eruption.

Rocks of this group are fine-grained and usually schistose. The mineral assemblage of each is very similar, the dominant constituents being plagioclase, hornblende and quartz. Biotite is usually more abundant than accessory and has apparently formed to some extent at the expense of hornblende, as a retrograde effect. Epidote, iron ore and sphene are accessory minerals. Minor quantities of relict brown hornblende occur as small grains in two of the sections prepared. The approximate modes are shown in Table I. The varieties designated as plagioclase hornblende schists differ only in a higher content of plagioclase.

TABLE I

Approximate Modes of Amphibolites and Plagioclase Hornblende Schists

ROCK No.	106	124	121	109
Name	Plagioclase Hornblende Schist	Plagioclase Hornblende Schist	Amphibolite	Plagioclase Hornblende Schist
Plagioclase - - - -	50	50	10	50
and				
Composition - - - -	Ab70	Ab70	Ab70	
Quartz - - - - - - -	20	20	10	20
Hornblende - - - -	15	15	70	25
Biotite - - - - - - -	10	10	10	acc.
Epidote - - - - - -	acc.	acc.		acc.
Iron Ore - - - - - -	acc.	acc.		acc.
Sphene - - - - - - -	acc.	acc.	acc.	acc.

One of these rocks (121) is a *fine-grained amphibolite* of dark grey colour. In section, well-developed individuals of hornblende form an interlocking meshwork of radially orientated prisms, and small plagioclase and quartz grains occupy interstices. Shearing stress has slightly modified the texture, as small flakes of biotite which appear to have been developed from hornblende as a result of stress have a strict parallel arrangement in contrast to the hornblende. Sphene is accessory.

DIORITIC GNEISSES

Dioritic gneisses are important components of the gneissic complex at Pidinga. They occur extensively and, apart from the presence of enclosed schlieric remnants of finer grained amphibolites and plagioclase hornblende schists, they are reasonably uniform in both constitution and general field appearance.

The mineralogical characteristics of the group are the abundance of plagioclase and quartz, with biotite and/or hornblende as the mafic constituents. Modes are shown in Tables II and III. The quartz and plagioclase normally form a granoblastic mosaic with indistinct boundaries to individual grains, but occasionally the plagioclase is lath-shaped. The parallel arrangement of such elongated

feldspar crystals and the mafic minerals are responsible for a gneissic structure. In some varieties, foliation of plagioclase and hornblende is very marked. Superimposed effects of dynamic metamorphism have caused partial granulation of the mineral assemblage in a number of these rocks.

TABLE II

Approximate Modes of Hornblendic Dioritic Gneisses

ROCK No.	148	2	93	118
Name	Banded Dioritic Gneiss	Lineated Dioritic Gneiss	Banded Dioritic Gneiss	Banded Dioritic Gneiss
Plagioclase - - - - -	55	50	65	40
and				
Composition - - - - -	Ab_{65}	Ab_{60}	Ab_{75}	
Quartz - - - - - - -	15	5	acc.	acc.
Hornblende - - - - -	15	25	30	45
Biotite - - - - - - -	15	10	acc.	acc.
Epidote - - - - - -		acc.	acc.	
Iron Ore - - - - - -	acc.	acc.	acc.	5
Sphene - - - - - - -		acc.	acc.	

TABLE III

Approximate Modes of Biotitic Dioritic Gneisses

ROCK No.	1	112	108	92	22
Name	Dioritic Augen-gneiss	Dioritic Augen-gneiss	Dioritic Gneiss	Dioritic Gneiss	Dioritic Gneiss
Plagioclase - - - - -	40	65	50	65	70
and					
Composition - - - - -	Ab_{70}	Ab_{75}		Ab_{65}	Ab_{70}
Potash feldspar - - -	acc.				
Quartz - - - - - - -	35	10	35	20	20
Hornblende - - - - -					
Biotite - - - - - - -	20	20		10	10
	acc.	acc.	10	5	acc.
Iron Ore - - - - - -	acc.	acc.	acc.	acc.	acc.
Sphene - - - - - - -		acc.	acc.		

The plagioclase is consistently of a composition near Ab_{70}. Twinning is often vague or absent. Other properties are a patchy distribution of saussuritic alteration and, more rarely, a zonary extinction.

Biotite, or chlorite pseudomorphous after biotite, is the usual ferro-magnesian constituent of the fine-medium grained types, whereas hornblende is chiefly developed in the coarser varieties. The latter occur in proximity to granitic masses discussed later (see page 39) and are apparently a more highly metamorphosed facies of the biotite-bearing gneisses. The replacement of biotite by hornblende can be observed in thin section, and the nature of the change is illustrated by the modes. Hornblende takes the place of biotite plus quartz, and the plagioclase becomes a slightly more basic variety. Epidote occurs in minor amounts as an associate of biotite and can be seen to be forming at the expense of

the degradation of that mineral to chlorite and iron ore. Sphene is a common accessory of the hornblendic rocks and was probably a released mineral during the conversion of biotite to hornblende. Ilmenite, pyrites, apatite and zircon are other accessory minerals.

Thus it is considered that the variety of rock types within the group of dioritic gneisses is determined largely by the stage of metamorphism to which they have been subjected. In brief, the dominant types are:

granulated plagioclase quartz biotite gneiss;
plagioclase quartz biotite augen-gneiss;
lineated plagioclase hornblende biotite gneiss;
banded plagioclase hornblende biotite gneiss.

The dioritic gneisses occur in close association with amphibolites and plagioclase hornblende schists of remarkably similar mineral composition (see Tables I, II and III), and these types grade imperceptably from one to the other and are, no doubt, genetically related. They all appear to have been derived by various stages of metamorphism of igneous rocks, mainly doleritic, or by metamorphism of a series of dolerites and diorites related to the one magma. The gradation of amphibolite to dioritic gneiss observed at Pidinga is also a pronounced metamorphic feature of the same series of Precambrian rocks which form an extensive coastal shelf at Rocky Point.

Good exposures of the dioritic gneisses occur in the bed of a small lagoon near Pidinga Rockhole. A specimen from this locality (2) is a *lineated plagioclase hornblende biotite gneiss* of medium grain and dark colour. The elongated minerals have a common orientation, giving rise to a pronounced lineation.

The thin-section reveals a rigid parallel arrangement of the mineral assemblage. The plagioclase ($Ab_{60}\ An_{40}$)is the dominant constituent and forms a matrix of elongated laths in which are embedded hornblende and biotite. Quartz is a minor constituent. The hornblende is present as sub-idioblastic crystals with numerous inclusions of iron ore. Columnar crystals and granular aggregates of clinozoisite are present in small quantity in association with the biotite.

A dioritic gneiss also comprises portion of a small outcrop at the eastern end of Ifould's Lake (100) and is similar in many of the microscopic features to those of Pidinga. In addition to the normal components of the dioritic gneisses, however, skeletal crystals of garnet, and xenoblastic clinozoisite derived by the alteration of plagioclase, are also important constituents, and rutile is a common accessory mineral.

Flaser Plagioclase Quartz Dyke Rocks

Several acres of uniform white flaser rock consisting of medium-grained plagioclase and quartz are exposed on the southern portion of the small lake at Pidinga designated Lake C. The contact with the surrounding rocks is hidden by lake deposits.

Microscopically, this rock (145) is a medium to coarse-grained *leucocratic plagioclase quartz augen-gneiss*. The section is composed essentially of plagioclase augen with attrited margins set in a finely granulated and orientated matrix of plagioclase and quartz. The plagioclase is of composition $Ab_{70}\ An_{80}$. Also present is one porphyroblast of clear microcline and occasional small irregular grains of micrographic microperthite. Sericite and muscovite have developed along cracks in the feldspar as a result of shear. Quartz is foliated into lenticular masses with mosaic structure.

Another specimen from the same occurrence (7) has been considerably modified in composition by later introduction of potash feldspar.

Identical rocks occur in many places at Lake Tallacootra as narrow dykes which have been particularly resistant to erosion to form discontinuous wall-like outcrops, but their relation to the other gneisses is again obscured by a superficial coverage.

Aplitic Veins and Segregations

A feature of the older series of gneisses is the abundance of dykes of quartz and feldspar-quartz pegmatites, and irregular segregations of aplitic or pegmatitic material. They vary considerably in composition and appearance throughout the area generally, and no attempt has been made to distinguish them as related to one or another parent type. Thin-sections have been prepared of two of the finer-grained varieties.

A section of a medium-grained pink *gneissic aplite* (15) shows that the slight tendency towards foliation is effected by the parallel arrangement of the small amount of biotite present and occasional lenticular quartz aggregates in an otherwise non-directional mosaic of equi-granular plagioclase, potash feldspar and quartz. Effects of dynamic metamorphism are illustrated locally by areas of crushed grains wedged between more resistant crystals, giving rise to a mortar structure. The potash feldspar is perthitic on the borders of most grains. Accessory are iron ore, sericite and muscovite. An idioblastic monoclinic yellow-brown mineral included in the plagioclase has the properties of orthite.

Another variety is a *flaser granite aplite* (4). It is a very fine-grained dense felsic rock which has suffered extreme shear.

The whole of the rock has been reduced to a fine-grained aggregate of mainly microcline and quartz, with subordinate plagioclase ($Ab_{70}\,An_{30}$) and biotite, showing mortar structure. A few microcline grains that have withstood the shattering effects beyond being reduced to lenticular remnants are of slightly larger dimensions. The individuals of the assemblage show elongation in the direction of movement. Quartz, in particular, occupies long discontinuous bands and lenses. Iron ore is accessory.

Basic Rocks

In a few localities where the country rock is otherwise composed of a diversity of dioritic gneisses and amphibolites, there are some cross-cutting narrow dykes of dense basic to ultrabasic rock, with sharp contacts, which can be traced as such for as far as the exposures permit. These are of younger origin than the complex of gneisses. Specimens of two of these dykes were sectioned. Both showed metamorphic effects, including the development of prehnite and anthophyllite respectively. The latter rock is apparently a metamorphosed pyroxenite.

Included in this section is the occurrence of peridotite rock which also appears to bear an intrusive relation to the dioritic gneisses, etc. This ultrabasic rock forms a bold isolated outcrop, elongated and covering an area of about half an acre. There are several highly basic dykes similar to those described in the preceding paragraph in this vicinity and it seems likely that they are related genetically to this plutonic rock. The metallic appearance of the pyroxene constituent of the peridotite has evidently attracted the attention of prospectors as the outcrop is enclosed by lease pegs.

Prehnitised dolerite dyke—a dense greyish-black rock of extremely fine grain (129).

In thin section, a palimsest ophitic texture is still in evidence and shearing effects are absent. Conspicuous tabular phenocrysts of prehnite, pseudomorphous after plagioclase feldspar, occur at random in a microcrystalline groundmass composed of a matte of abundant plagioclase, chlorite, prehnite, iron ore and quartz. Staining due to limonite obscures portion of the slide.

Plagioclase anthophyllite quartz dyke rock—This (105) is a fine-grained dense greenish-grey dyke rock of high specific gravity in which none of the constituent minerals can be determined in the hand specimen.

Microscopically, the texture is controlled by abundant crystals of the colourless amphibole anthophyllite comprising a mesh-work of interlocking prismatic crystals and columnar aggregates and set in a fine-grained matrix of plagioclase and quartz. The plagioclase includes some anthophyllite and is a basic oligoclase with poorly defined twins. The minor amount of quartz is present as very small blebs. The anthophyllite is studded with numerous minute inclusions. Rutile is accessory.

Diallage olivine peridotite rock—A specimen (56) in which pyroxene with a metalloidal lustre on the weathered surfaces can be seen to be the chief constituent. Brown biotite is visible in the hand specimen but absent in the slide. There are no obvious effects of metamorphism.

A thin-section study reveals that the rock consists of the pyroxene diallage, olivine and brown hornblende, and the texture is holocrystalline hypidiomorphic granular, modified by the occasional development of diallage phenocrysts. Diallage is the dominant component of the assemblage. Brown hornblende occurs as an overgrowth on the diallage and has evidently formed at its expense. Plagioclase is present in subordinate amounts (about 5%). Twinning is not sharp but the wide twin laminae are typical of basic plagioclase. Olivine is represented by colourless anhedra with polygonal outlines. It is altered to serpentine on the margins and along fractures.

The Granitic Augen-Gneisses and Associated Migmatites

The red granitic augen-gneisses are among the more common of the types constituting the Precambrian outcrops at Pidinga. They occur at intervals as elongated or lenticular masses which vary from just a few yards to more than half a mile in longer dimensions. The appearance is uniform in each of the many outcrops, in contrast with the heterogeneous nature of the types already described as components of the surrounding mixed gneisses. The outcrops are often of a bold nature, as they have resisted weathering to a greater extent than the other members of the Precambrian basement (pl. III, fig. 2). A typical example is the several acres of rock exposed at Pidinga Rockhole.

The granitic gneisses are younger than the mixed gneisses which they replace, but their relation to the basic dyke rocks is not evident. Their elongation corresponds with the general gneissosity of the complex as a whole, and they are thus considered to have been emplaced during a period of regional metamorphism of which there is evidence throughout the area, and certain features are presented which suggest that metasomatic processes were responsible for their formation. A major consideration in the study of genetics of the granitic gneisses is the occurrence of partially feldspathised dioritic gneisses and amphibolites in proximity to their margins, and rocks of this category are also described in this section. The widespread pegmatisation of the older mixed gneisses (see p. 38) may have taken place at the same time and in a similar way but such a relationship cannot be confirmed due to the discontinuous nature of the exposures.

Petrographic Characters of the Granitic Augen-Gneisses

A petrographic study of the granitic augen-gneisses confirms that the mineral assemblage and structure of the rocks from separate outcrops are reasonably constant.

The essential constituents in order of abundance are potash feldspar, quartz, plagioclase and biotite. The plagioclase is of composition intermediate between oligoclase and andesine. Epidote, iron ore, sphene, tourmaline, apatite and zircon are accessory minerals. Garnet is another minor constituent but is not represented in the thin-sections prepared from these rocks. The modes of typical specimens are shown in Table IV.

TABLE IV

Approximate Modes of Granitic Augen-Gneisses

ROCK No.	104	10	31	32
Name	Granitic Augen-gneiss	Granitic Augen-gneiss	Granitic Augen-gneiss	Granitic Augen-gneiss
Plagioclase and	10	25	acc.	5
Composition	Ab70	Ab70		
Potash feldspar	45	40	60	60
Quartz	35	25	30	30
Biotite	5	5	5	5
Epidote	acc.	5	acc.	acc.
Iron Ore	acc.		acc.	
Sphene	acc.			

The augen structure is controlled by lenticular porphyroblasts of feldspar, dominantly orthoclase and to a lesser extent microcline or plagioclase, arranged parallel in a finely granulated matrix. There is evidence that the stress effects promoted the conversion of orthoclase to microcline, and in other cases, perthite. The effects of the superimposed dynamic metamorphism have almost completely destroyed the former texture, but occasionally areas preserved from crushing show granoblastic relations with indistinct crystal boundaries.

A section of one rock (104) shows unusual relations of the plagioclase and potash feldspar. In one instance, where a large porphyroblast of microcline adjoins a crystal of plagioclase, the margin of the latter has been cleared of inclusions and is in optical continuity with the potash feldspar, although the R.I. is still greater than that of the microcline. The remaining portion of the plagioclase grain contains a micrographic intergrowth of potash feldspar. Another relic grain of corroded and saussuritised plagioclase is rimmed completely with clear microcline. Elsewhere, rounded blebs of clear potash feldspar are common throughout the dusty plagioclase.

The potash feldspar is quite fresh and clear in comparison to the highly dusted and partially saussuritised plagioclase, and the large porphyroblasts are often surrounded by irregular blebs of perthite and anti-perthite. They carry occasional large inclusions of biotite, epidote and quartz arranged parallel to the gneissosity. A majority show vague cross-hatching.

Tourmaline is present in the section of rock (32) where it occurs as small idioblasts pleochroic from pale yellow to dark green-black. The crystals have a random orientation in an otherwise rigidly gneissic environment suggesting a late stage introduction of that mineral.

FELDSPATHISATION PHENOMENA

Field observations combined with petrological studies reveal features which suggest that the granitic gneisses may owe their origin to metasomatic replacement (chiefly feldspathisation) of pre-existing dioritic gneisses and amphibolites, etc., rather than normal igneous intrusion. Phenomena which are considered to demonstrate metasomatism are outlined below:—

1. The contacts of the granitic gneiss with the dioritic gneiss and other rock types of the metamorphic complex are often of a vague transitional nature. In the exposures east of the Pidinga Shed Tanks and near Pidinga Rockhole, the margins of the granitic gneiss are intermingled in a lit par lit fashion (pl. III, fig. 4) with the adjacent dioritic gneisses to form rocks of a truly migmatitic

character. In other instances, where the change from one type to the other appears abrupt to the unaided eye, a thin-section study shows that potash feldspar has nevertheless been introduced interstitially for considerable distances beyond the boundaries of the granitic gneiss. The gradation from dioritic gneiss through migmatites to granitic gneiss is illustrated in Table V. *Rocks No. 24, 23* and *22* were collected as a series (see geological plan) at regular distances (10, 20 and 30 yards respectively) from the contact of the granitic gneiss near the Pidinga Shed Tanks. Thin-sections of rocks of migmatitic character, the modes of which are included in Table V, are described in the following section.

TABLE V

Partial Modes of Rocks Gradational from Dioritic Gneiss to Granitic Gneiss

Rock No.	Name	Plagioclase and Composition	Potash feldspar	Quartz	Biotite
22	Dioritic Gneiss - - - - - - -	70 Ab70	—	20	10
1	Dioritic Augen-gneiss - - -	40 Ab70	acc.	35	20
23	Partially Felds-pathised Dioritic Gneiss - - -	65 Ab70	10	10	10
24	Partially Felds-pathised Dioritic Gneiss - - -	45 Ab70	20	25	5
29	Highly Felds-pathised Dioritic Gneiss - - -	20 Ab70	40	30	5
104	Granitic Augen-gneiss - - -	10 Ab70	45	35	5

2. The plagioclase which is constantly present as a constituent of the granitic gneisses is identical in general microscopic appearance, form (lath-shaped where preserved from granulation) and composition ($Ab_{70}\,An_{30}$) to that which characterises the older dioritic gneisses and amphibolites. It is usually represented by corroded relicts or aggregates.

3. The potash feldspar is quite fresh and free from impurities in comparison to the plagioclase, which is dusted with minute inclusions and products of incipient saussuritisation.

4. Possible stages in the replacement of the plagioclase by potash feldspar are illustrated in one specimen of the granitic gneiss (104) and have already been described.

DESCRIPTION OF MIGMATITES

The rocks described hereunder are partially feldspathised rocks (chiefly dioritic gneisses) collected from near the contacts with the granitic gneisses. Partial modes of several of the thin-sections described are shown in Table V.

Partially feldspathised dioritic gneiss (24)—Medium-grained dark bands rich in clear plagioclase, biotite and quartz grade into pink coarser-grained granitic bands.

The gneissic structure is imparted by parallel orientated biotite flakes, in an otherwise xenomorphic inequigranular matrix of rounded feldspar and quartz grains. This has been modified by shear, resulting in the comminution of crystal boundaries against one another, and cracks through individual crystals.

Both plagioclase and potash feldspar are essential constituents, but the latter is restricted to narrow bands with quartz which pass gradationally into the main mass of the rock, where plagioclase is the dominant feldspar. The plagioclase is usually untwinned. It is of composition $Ab_{70}\,An_{30}$. The potash feldspar is mainly microcline but there are also patches of a xenomorphic perthite mosaic. The microcline is quite clear in contrast to the plagioclase which carries segregations of impurities. Quartz is abundant throughout the slide. Chloritised biotite and sub-idioblastic epidote are essential constituents of the plagioclase-rich areas. Muscovite, iron ore, zircon and apatite are accessory.

In another specimen (23) the introduced potash feldspar is restricted to small isolated lenticular zones.

The bulk of the rock consists of medium-grained colourless plagioclase, biotite and quartz. There are lighter-coloured discontinuous bands and clots rich in pink potash feldspar, with a sharp demarcation at the margins in the hand-specimen.

The texture is controlled by the predominant mineral, plagioclase $Ab_{70}\,An_{30}$, which forms a granoblastic aggregate of rounded grains with a tendency towards directional orientation parallel to the gneissosity. Biotite flakes have a rigid parallel alignment and quartz is segregated into lenticular mosaics.

The mineral assemblage varies in some local elongated clots, where microcline is the predominant feldspar and carries aggregates of sphene. The texture and structure are nevertheless constant throughout, having been impressed by dynamic stresses which resulted in the shattering and granulation of the mineral constituents. These effects have been in part healed by local recrystallisation.

The plagioclase is studded with abundant small inclusions. Twinning is indistinct or absent. Lines of inclusions parallel the twin planes or former twin planes. The microcline is quite clear with poorly defined gridiron structure.

Biotite occurs as small xenoblasts in an advanced stage of alteration to green chlorite. Epidote is present in quantity as xenoblastic aggregates or prismatic subidioblasts of moderate dimensions, often associated with and including chloritised biotite. Large yellow-brown sphene grains are only slightly pleochroic.

Occasional rounded grains of calcite are interstitial amongst the plagioclase or included in it. Other accessory minerals are apatite, iron ore, muscovite and zircon.

ACKNOWLEDGMENTS

The writer is highly indebted to Mr. S. B. Dickinson, Government Geologist of South Australia, for providing an opportunity to carry out the field work and making available facilities of the Mines Department, as well as most helpful criticisms and suggested research during preparation of the manuscript. He also wishes to thank Professor Mawson and other friends and colleagues who contributed advice, and for technical assistance by Miss I. Crespin (Commonwealth Palaeontologist) and Mr. B. C. Cotton, Conchologist at the Adelaide Museum.

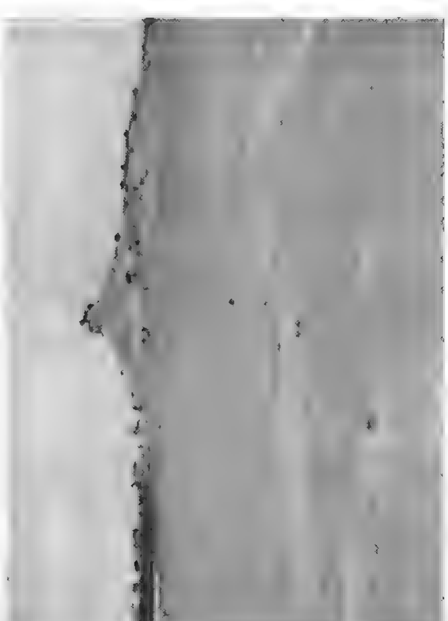


Fig. 1
"Island" on the Main Pidinga Lake. Rock is fossiliferous limestone.

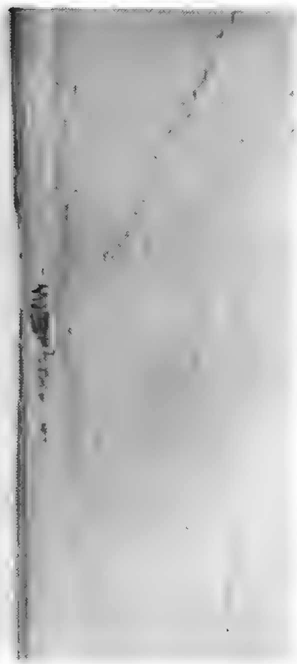


Fig. 2
Panorama across the Main Tallacootra Lake. Precambrian rocks outcrop in the centre.

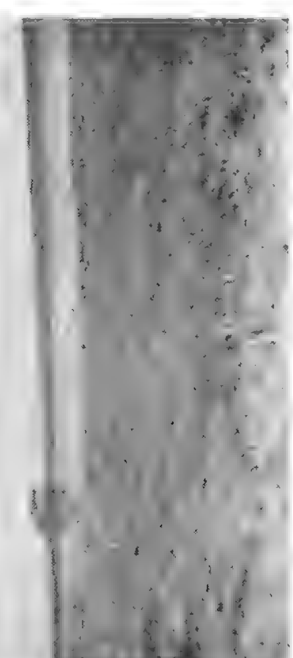


Fig. 3
View across portion of the Main Pidinga Lake.

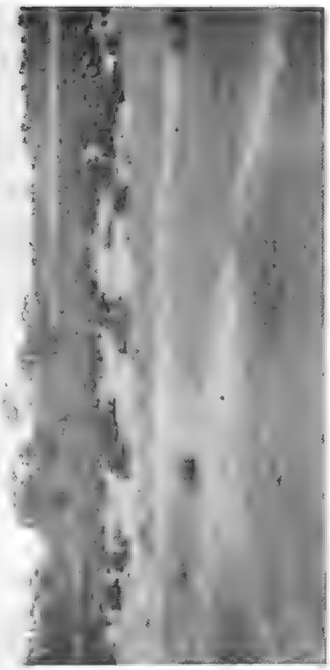


Fig. 4
Timbered depression at the south-western extremity of the Main Pidinga Lake. The low cliffs in the background are fossiliferous limestone.

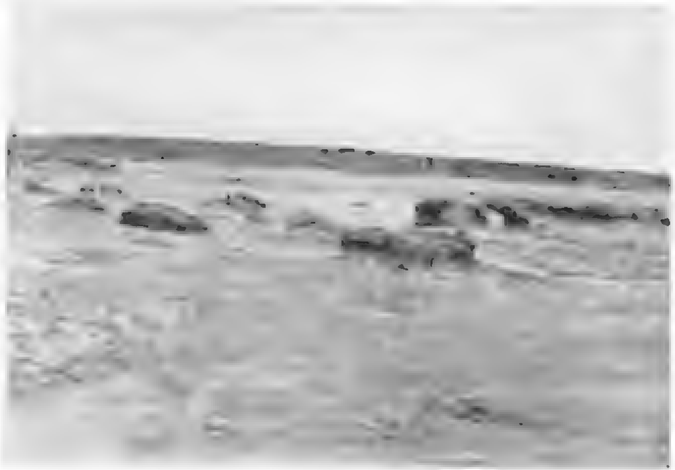


Fig. 1

Precambrian dioritic gneisses outcropping on the edge of a lagoon near Pidinga Rockhole.

Fig. 2

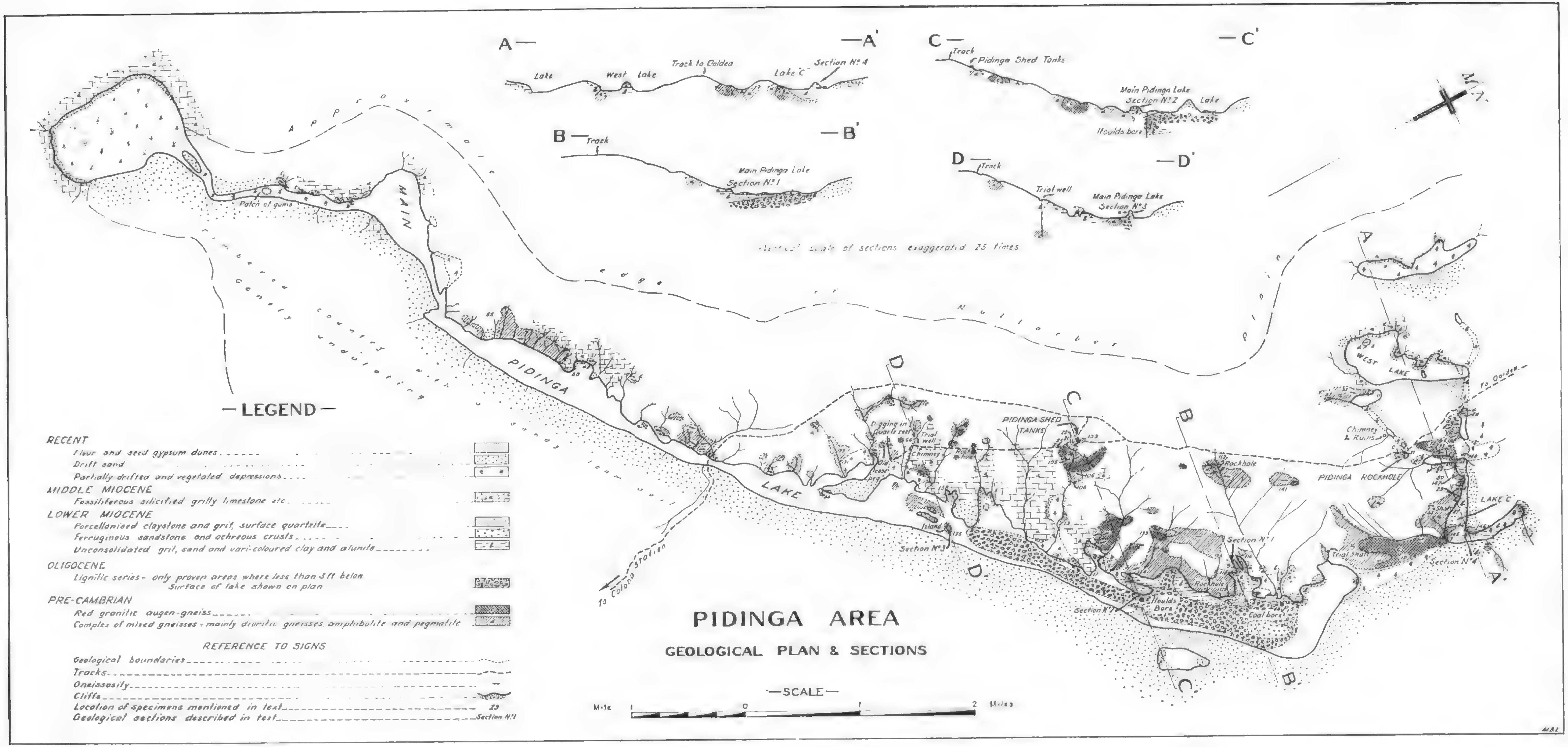
Precambrian granitic gneiss outcropping near Pidinga Rockhole.

Fig. 3

Streaks of amphibolite in a complexity of gneiss, Pidinga.

Fig. 4

Coarse lit par lit structure of granitic augen-gneiss and dioritic gneiss near Pidinga Rockhole.



PIDINGA AREA
GEOLOGICAL PLAN & SECTIONS
A — — A'
Lake
West Lake
Track to Ooldea
Lake 'C'
Section No. 4
B — Track — B'
Main Pidinga Lake
Section No. 1
C — Track
Pidinga Shed Tanks — C'
Main Pidinga Lake
Section No. 2
Lake
Moulds bore
D — Track — D'
Trial well
Main Pidinga Lake
Section No. 3
Vertical scale of sections exaggerated 25 times
Approximate edge of Nullarbor plain
Timbered gently undulating country with sand loam
MAIN
PIDINGA
LAKE
Patch of gums
Digging in Quartz reef
Trial well
Chimney
PIDINGA SHED TANKS
Rockhole
PIDINGA ROCKHOLE
WEST LAKE
To Ooldea
Chimney & Ruins
LAKE 'C'
Trial Shaft
Island
Section No. 3
Section No. 1
Section No. 2
Section No. 4
Moulds Bore
Coal bore
Rockhole
To Colona Station
— LEGEND —
RECENT
Flour and seed gypsum dunes
Drift sand
Partially drifted and vegetated depressions
MIDDLE MIOCENE
Fossiliferous silicified gritty limestone etc.
LOWER MIOCENE
Porcellanized claystone and grit, surface quartzite
Ferruginous sandstone and ochreous crusts
Unconsolidated grit, sand and vari-coloured clay and alunite
OLIGOCENE
Lignitic series – only proven areas where less than 5 ft below surface of lake shown on plan
PRE-CAMBRIAN
Red granitic augen-gneiss
Complex of mixed gneisses – mainly dioritic gneisses, amphibolite and pegmatite
REFERENCE TO SIGNS
Geological boundaries
Tracks
Gneissosity
Cliffs
Location of specimens mentioned in text
Geological sections described in text
23
Section No. 1
— SCALE —
Mile 1 0 1 2 Miles

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AN OCCURRENCE OF CROCIDOLITE NEAR ROBERTSTOWN, SOUTH AUSTRALIA

BY A. P. WYMOND AND R. B. WILSON

Summary

This paper discusses the petrology and mineralogy of some crocidolite deposits near Robertstown, South Australia. The crocidolite is associated with dolerites which have been intruded into the Beaumont Dolomites of the Adelaide System. Analysis shows the mineral to be richer in magnesis than normal riebeckite.

AN OCCURRENCE OF CROCIDOLITE NEAR ROBERTSTOWN, SOUTH AUSTRALIA

By A. P. Wymond and R. B. Wilson*

[Read 12 October 1950]

SUMMARY

This paper discusses the petrology and mineralogy of some crocidolite deposits near Robertstown, South Australia. The crocidolite is associated with dolerites which have been intruded into the Beaumont Dolomites of the Adelaide System. Analysis shows the mineral to be richer in magnesia than normal riebeckite.

I. INTRODUCTION

The occurrence of crocidolite asbestos in the Robertstown area has been known for many years, and the mining of this mineral has taken place in several localities. Reports of the mines opened up in sections 2, 2A, and 3A of the Hundred of Bright are given in Mining Reviews of the South Australian Department of Mines, and a list of these is included in the Bibliography.

The deposits which have been investigated in this instance, occur in Sections 30, Hd. of Bright, 295, Hd. of Apoinga, and 26, Hd. of Bright (Nos. 1, 2 and 3 Asbestos localities respectively) all of which lie between 4 and 8 miles north of Robertstown.

The present investigations were assisted by a Commonwealth Research Grant, the petrology being carried out by one of us (R. B. W.) and the mineralogy and drafting of the paper by the other (A.P.W.).

II. GEOLOGICAL SETTING OF CROCIDOLITE DEPOSITS

The crocidolite occurs in association with meta-dolerites which have intruded Beaumont Dolomites. The Adelaide System beds in this area have been simply folded, forming a series of broad anticlines and synclines with north-south axes.

The structural control influencing the intrusion of the dolerite is an extensive strike fault, a southerly extension of the Kooringa Fault of the Burra area (1). Severe crushing and brecciation is evident adjacent to this fault zone.

III. CROCIDOLITE HOST ROCKS

(a) *Meta-dolerites*

What may have originally been doleritic intrusions have been altered, probably by late magmatic action, to albite-biotite types, here termed "meta-dolerites." Rocks of this group differ widely in appearance, but in surface outcrop are all soft and friable. The persistent occurrence of albite and green biotite is their most common feature.

They have the characteristic dolerite texture produced by inter-locking feldspar laths (8788, 8788A, 8789). The feldspar is always albite (Ab96), and varies greatly in size in two (8788, 8788A), being present as phenocrysts up to 5mm. long. The albite laths are crowded with fine inclusions of green mica, sericitic mica and iron oxides. Green biotite often occurs as decussate aggregates up to 4mm. in diameter. The amount of this biotite is very variable in the different rocks, being so abundant in some (8792) that the texture may be more aptly described as hornfelsic, though a relict doleritic texture may be seen.

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In the groundmass, green biotite and small feldspar laths are abundant, while ilmenite, rutile, occasional apatite and secondary calcite are accessory.

There are some vesicular types (8793) with vesicles up to 4mm. in diameter filled with calcite and pink microcline (the calcite forming the core), and all set in a fine-grained holocrystalline groundmass. A few albite phenocrysts are also present.

Crocidolite is not common, being found only in one (8792) as small fibrous masses, intimately associated with the feldspar.

(b) *Tourmalinized rocks*

Tourmalinized meta-dolerites are associated with the normal type in several places, the amounts of tourmaline being very variable (8794-8795). A poorly defined relict doleritic texture persists in these. The tourmaline occurs as large skeletal crystals with inclusions of albite, which often have similar optical orientation, suggesting replacement of feldspar by tourmaline. Albite (Ab94) is present as irregular laths with some interlocking texture. What appears to be talc is abundant as small colourless plates, and biotite, crocidolite, ilmenite and rutile are also present.

Vesicular meta-dolerites have also been tourmalinized. Some of the vesicles are filled with microcline (8795 — c.f. 8793 above) while in others (8790) the vesicles, up to 5mm. in diameter, are occupied by calcite and chalcedony, and are set in a fine-grained matrix consisting essentially of tourmaline showing decussate structure; rutile, biotite, albite and apatite being accessory.

All these rocks appear to be meta-dolerites which have undergone varying degrees of tourmalinization.

(c) *Dolomites*

At another locality (No. 3) crocidolite is found in a zone of crushed dolomite marble. The host rocks are crocidolite-talc-albite marbles (8797 and 8798) which are light coloured coarse-grained rocks, and contain abundant blue prisms of crocidolite and white albite (Ab92) crystals, set in a matrix of dolomite. The fibrous aggregates of crocidolite are in some places intergrown with talc. Rutile and apatite are accessory.

IV. OCCURRENCE OF CROCIDOLITE

Small occurrences of crocidolite are widely scattered throughout a large area, but only three were examined in detail.

At the No. 1 locality, crocidolite was found as small veins, or larger masses, cutting meta-dolerite, also associated with a vesicular tourmaline rock (8790). Costeens have been dug in several places, but due to generally poor exposures, the field relations of the various rock types could not be determined.

At No. 2 locality (2), a small quarry has been opened up to work the asbestos, which here occurs as a large number of veins up to 4 inches wide, cutting meta-dolerite. Patches rich in tourmaline are prominent.

The occurrence at No. 3 locality was slightly different. Here, dolomite carrying crocidolite was found in a zone about 30 yards wide within an area of intensely crushed marble.

The mineral occurs in two different forms; as relatively large masses (up to 2 or 3 feet across) of short interlocking fibres, and in relatively thin veins (up to 4 inches) containing both cross and slip fibre. The more massive variety, which predominates at No. 1 locality does not readily break

into fibres, but on crushing, its fibrous nature becomes evident. Much of this material contains rhomb-shaped crystals of ferroan dolomite. The crocidolite is a dark blue colour with a silky lustre. Thin sections show three prominent directions of fibres, intersecting at approximately 60°, producing a triangular intergrowth pattern. In the small triangular spaces thus produced, basal sections of the typical amphibole shape often occur. The fibrous variety came from No. 2 locality and is of commercial importance. Some physical properties of similar material from the Hundred of Bright have been published by the Mines Department of South Australia (3 and 4).

V. OPTICAL PROPERTIES

The optical properties of the massive and fibrous varieties are set out below. Slight differences between the two varieties may be noted with respect to Extinction Angle and Refractive Index.

Colour: Light Blue, strongly pleochroic; X = light sky blue, Y = yellow to greenish yellow, Z = violet.

Birefringence: Weak to moderate, Max. approximately ·014, masked by high absorption.

Orientation: Length fast.

Interference Figure: Biaxial negative, 2V, approximately 40°.

Extinction Angle: (a) massive form $X' \wedge 110$ variable to 15°.
Basal Sections symmetrical.
(b) Fibrous: $X \wedge C = 0°\text{-}5°$

Refractive Index: (a) massive: $\alpha = 1{\cdot}6652 \pm {\cdot}0005$
$\gamma = 1{\cdot}6775 \pm {\cdot}0005$
(b) fibrous; $\alpha = 1{\cdot}6682 \pm {\cdot}0005$
$\gamma = 1{\cdot}6820 \pm {\cdot}0005$

In each case the value for α must be considered the most accurate. Owing to the fibrous nature of the mineral, no value for β could be determined. (Observations were made using the thermal variation method under sodium light).

Although there are some slight differences, the two varieties may be considered as essentially the same material.

The mineral may be concluded to be a mixture of the glaucophane and riebeckite molecules, although it is not possible from the optical data available to determine the proportions in which the two molecules are present.

VI. CHEMICAL COMPOSITION

A sample of pure long fibre asbestos from No. 2 locality was analysed with the results shown in table I (1). For comparison, analyses of Western Australian and of another South Australian occurrence are shown.

TABLE I

	I	II	III
SiO_2	54·87	53·48	51·94
Al_2O_3	1·78	5·32	0·24
TiO_2	0·68	—	0·01
Fe_2O_3	16·41	15·16	18·93
FeO	5·38	3·44	15·25
MgO	11·34	10·90	3·94
CaO	0·45	0·72	0·40
Na_2O	6·77	6·30	6·00
K_2O	0·25	0·70	0·26
H_2O+	1·62	2·32	2·67
H_2O-	0·51	0·72	0·72
MnO	Tr	present	0·01
CO_2	nil	0·22	nil
	100·06	99·28	100·37

I. Long fibre crocidolite, 4 miles N. of Robertstown (No. 2 locality): Analyst, A. P. Wymond.

II. Crocidolite, 9 miles north-east of Robertstown: Analyst, W. S. Chapman (5).

III. "Crocidolite Proper" from 8 miles south-east of Willi Wolli Springs, Hammersley Range, W.A. Analyst, J. N. Grace (7).

In Table II. the Structural Formula of the crocidolite (Table I. (1)) has been calculated.

TABLE II

		Metal Atoms		Metal Groups
SiO_2	54·87	7.86		8·00
Al_2O_3	1·78	0·30	0.14 0.16	
TiO_2	0·68	0·07		1·99
Fe_2O_3	16·41	1·76		
FeO	5·38	0·65		3·48
MgO	11·34	2·43		
CaO	0·45	0·07		1·99
Na_2O	6·77	1·89		
K_2O	0·25	0·03		
H_2O+	1·62	1·56		1·56
H_2O-	0·51			
MnO	Tr.			
CO_2	nil			
	100·06			

This gives the formula:— $(O, OH)_2\ Na_2\ (MgFe^{II})_3\ Fe^{III}_2\ (SiAl)_8\ O_{22}$.

The analysis and calculated formula show that the composition differs from Riebeckite by having a higher percentage of MgO, and a moderate amount of Al_2O_3. The presence of a small amount of TiO_2 is in keeping with the abundance of rutile and ilmenite in the associated rocks.

Riebeckite and Glaucophane are miscible in all proportions (6), and the formula of the Robertstown mineral indicates major replacement of Fe^{II} of the Riebeckite molecule by Mg, and slight replacement of Fe^{III} by Al. The optical properties agree more closely with those of Riebeckite than of Glaucophane. Hence the mineral may be termed a Magnesian Riebeckite.

VII. GENESIS OF THE CROCIDOLITE

The crocidolite described herein is associated with late magmatic soda metasomatized intrusions which show doleritic texture. Varying degrees of tourmalinization are also recorded. A feature of the final metasomatic phases is the crocidolite, which has formed from iron-and-soda-rich solutions, and has filled joint planes and fissures in the meta-dolerite, and in some places has invaded the surrounding dolomite. The presence of a high percentage of magnesia in the crocidolite may be due to assimilation from the dolomite by the late magmatic solutions.

The genesis of the crocidolite is thus probably related to late magmatic activity associated with "doleritic" intrusions.

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Additional references to the Robertstown Crocidolite may be found in Mining Reviews 16, 23, 36, 78, published by the S. Aust. Department of Mines.

THE LIFE HISTORY OF PLAGIORCHIS JAENSCHI, A NEW TREMATODE FROM THE AUSTRALIAN WATER RAT

BY T. HARVEY JOHNSTON AND L. MADELINE ANGEL

Summary

1. An account of the anatomy of Plagiorchis jaenschi from the Australian water rat, Hydromys chrysogaster Geoff., var. fulvolateralis Gould, is given.
2. Two apparently distinct forms are shown to be the same, the differences being attributable to the state of preservation of the material.
3. Infection of Lymnaea lessoni was accomplished experimentally. This is believed (but not proved) to follow ingestion of the eggs.
4. The various stages in the life cycle, excluding the miracidium, are described.
5. The cercaria encysts in mosquito larvae, and also in crustaceans, Daphnia, Chiltonia and Cherax, of which the last-named, the yabbie, is believed to be the normal secondary intemediate host. Similar cysts have been found in yabbies from Tailem Bend. The cercaria also encysts, though rarely in the liver of the host snail.
6. Natural occurrences of the cercaria are recorded from Wood's Flat and Bow Hill; but it has not been found at Tailem Bend.

THE LIFE HISTORY OF PLAGIORCHIS JAENSCHI, A NEW TREMATODE FROM THE AUSTRALIAN WATER RAT

By T. Harvey Johnston and L. Madeline Angel *

[Read 12 October 1950]

Summary

1. An account of the anatomy of *Plagiorchis jaenschi* from the Australian water rat, *Hydromys chrysogaster* Geoff., var. *fulvolateralis* Gould, is given.
2. Two apparently distinct forms are shown to be the same, the differences being attributable to the state of preservation of the material.
3. Infection of *Lymnaea lessoni* was accomplished experimentally. This is believed (but not proved) to follow ingestion of the eggs.
4. The various stages in the life cycle, excluding the miracidium, are described.
5. The cercaria encysts in mosquito larvae, and also in crustaceans, *Daphnia*, *Chiltonia* and *Cherax*, of which the last-named, the yabbie, is believed to be the normal secondary intermediate host. Similar cysts have been found in yabbies from Tailem Bend. The cercaria also encysts, though rarely, in the liver of the host snail.
6. Natural occurrences of the cercaria are recorded from Wood's Flat and Bow Hill; but it has not been found at Tailem Bend.

The type as well as other representatives of the adult and larval stages have been deposited in the South Australian Museum. Acknowledgment is made of the generous assistance rendered by Messrs. G. G. and B. Jaensch of Tailem Bend and J. Brook of Bow Hill. The investigation was carried out in connection with the Commonwealth Research Grant to the University of Adelaide.

Plagiorchis jaenschi has been found in the lower part of the small intestine of six out of seven water rats, *Hydromys chrysogaster* Geoffr., var. *fulvolateralis* Gould, trapped by Messrs. G. G. and Bryce Jaensch along the banks of the River Murray at Tailem Bend—May 1938, April 1945, March 1947, May 1948, December 1949 (in one of two taken) and April 1950; also in all three *Hydromys* obtained for us by Mr. J. Brook from Bow Hill, near Mannum, also on the Murray, in April 1950. A water rat from Berri, May 1948, and one from the River Torrens, Adelaide, in July 1923, did not contain this trematode. The maximum number obtained on any one occasion was eighty, the worms being in various stages of growth. Fragments of the Murray prawn, *Palaemon australis*, and the yabbie, *Cherax destructor*, were usually present in the digestive tract. Because of unavoidable delay in examining the dead rats, the worms had in some cases become rather macerated before being collected, but these relaxed parasites permitted a more ready examination of the reproductive system. In two cases the parasites, when found, were much smaller and very strongly contracted, so that the reproductive organs were crowded into a small space. These latter worms were well preserved. Because of the marked dissimilarity in size and appearance it is proposed to refer to the two forms separately, the relaxed worms being described first. The type specimen belonging to this latter group is deposited along with paratypes in the South Australian Museum.

Egg-bearing specimens with pigmented vitellaria ranged from ·85 to 1·43 mm. in length and ·23 to ·37 mm. in maximum breadth, most of them being between ·93 and 1·0 mm. long and about ·3 mm. wide. Worms which reached

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the egg-bearing stage but which still contained very few eggs (1 - 20), measured from ·70 to ·77 mm. in length and ·2 to ·24 mm. in breadth. Nearly all relaxed specimens under ·74 mm. in length had not yet become ovigerous, although a worm ·71 mm. by ·22, and another ·73 by ·22, both possessed yolk follicles almost as numerous as they were in the smallest egg-bearing parasites. A worm ·72 mm. long possessed a single egg and its vitellaria were scanty, linear in arrangement and devoid of pigment. The worms were broadly rounded anteriorly, widest at the level of the oesophagus, and tapering very gradually to the level of the posterior testis, when they narrowed rather rapidly to terminate in a rounded tip.

The ventrally-directed oral sucker in ovigerous worms is approximately spherical, ·16 - ·17 mm. in diameter, and the acetabulum ·125 - ·15 mm. in diameter, though sometimes both suckers may be slightly wider than long or longer than wide. The oral sucker is thus somewhat larger than the ventral. The front end of the latter in mature worms is at about one-third of the body length. In immature relaxed worms the lengths of the anterior and posterior suckers are in the ratio of about 4 : 3, but in ovigerous specimens it is about 6 - 7 : 5. In worms ·36 to ·54 mm. long the oral sucker is about ·1 mm. in diameter and the acetabulum ·075 mm. These dimensions become increased (·175 by ·125 - ·15 mm.) as the worms become ovigerous, but do not increase further though the parasites may become much longer. It is more particularly the postacetabular region which increases in length as growth proceeds. In a worm ·36 mm. long the length of that region is 35% of the total body length; in those ·43 - ·47 mm. long, 39%; in a worm ·54 mm. long, 43%; in a worm ·73 mm. long and almost ovigerous, 47%; in a worm ·74 mm. long and just ovigerous, 59%; in a worm 1·43 mm., 58%. The sex pore is at about ·35 mm. from the head end, and close behind the point of bifurcation of the intestine. Spination, though evident in contracted worms, had disappeared from all relaxed specimens. Young worms may show the typical Y-shaped excretory bladder in preserved material.

The prepharynx is very short and lies above the hind edge of the oral sucker. The pharynx is spherical (·08 mm. diameter) or slightly elongate. The narrow oesophagus is very short, measuring about one-quarter or one-fifth of the length of the pharynx. The crura diverge almost at right angles to the longitudinal axis of the body and then curve posteriorly to lie more or less parallel with the edge of the body, their course being slightly sinuous. They terminate beside the posterior part of the stem of the excretory bladder.

The testes are each about ·17 mm. in diameter, though the posterior one may be rather narrower. The cirrus sac is relatively large and takes its origin at about the ovarian level, but on the opposite side. It then curves around and above the right side of the acetabulum, then inwardly and downwards, and approaches the metraterm as the two organs pass forwards to the genital pore. The sac passes directly ventrally to enter the latter. The length, measured along the curve, is about ·45 mm. and its breadth about ·07 mm. The posterior half or two-thirds of the organ serves as a seminal vesicle. Occasionally the sac lies in a more median, sinuous position, crossing above the acetabulum. The cirrus, when at rest, is closely folded in the anterior part of the sac. The fully extruded unarmed cirrus is about ·46 - ·53 mm. in length, and its width 15 - 17 μ except in the vicinity of its base where the breadth is about 42 μ.

The rounded ovary, ·08 by ·1 mm., is situated on one side a short distance behind the acetabulum, portion of the cirrus sac lying between the two organs. The oviduct passes inwards and posteriorly to meet the common yolk duct in the vicinity of the shell gland, the latter lying between the ovary and anterior testis. The uterus soon bends posteriorly and travels in a sinuous course between the testes, reaching almost to the level of the ends of the crura before returning

as the ascending limb which lies beside the descending limb. About the level of the shell gland, the ascending duct is thrown into a few loops as it makes its way to the left side of the worm. It passes below the inner end of the cirrus sac and then forwards in a ventral position beside (or sometimes above) the acetabulum. The metraterm is thin-walled. The yolk glands are extensive, covering the crural region and almost reaching the lateral edges of the worm. They extend from the level of the oesophagus to the free ends of the crura, terminating just behind, or just in front of, the posterior loops of the uterus. The follicles are irregularly rounded (12 - 15 μ diameter) or elongate. The two fields remain separate though some scattered follicles may occur in the oesophageal region between the lateral fields. The latter may approach very closely at their posterior ends. If we recognise the subgenus *Multiglandularis*, which is based on the distribution of the vitellaria, then our species would be *P.* (*M.*) *juenschi*. The main yolk ducts lie dorsally and transversely just in front of the anterior testis. There is a definite yolk reservoir. Eggs are 30 - 37 μ long by 17 - 22 μ wide, most of them being 32 - 34 μ by 17 - 20 μ.

Strongly contracted worms taken in June 1941 were, as stated above, well preserved when compared with those just described. The spines were short but abundant on the anterior region, becoming very low and scarcely recognisable under high power behind the level of the acetabulum. Similar spination was seen on metacercariae. Egg-bearing worms measured ·21 - ·56 mm. long by ·145 to ·25 mm. broad, the smaller individuals tending to be relatively wider than the longer. Those which were not ovigerous ranged from ·14 to ·31 mm. in length and ·088 to ·22 mm. in width. All strongly contracted worms were plump, with broadly rounded extremities and with a more or less marked ventral concavity involving the acetabulum and the region in front of it, sometimes extending to the oral sucker. Two cysts found in one host animal containing contracted worms measured ·11 by ·087 mm. and ·15 by ·112 mm., the latter having the stylet still in situ. A metacercaria freed from a cyst was ·137 by ·12 mm. These sizes fall approximately within the range of dimensions of cysts obtained from experimentally infected crayfish (120 μ by 98 μ to 173 by 158 μ; average 150 by 124 μ).

In the larger strongly contracted worms the suckers tend to be rather broader than long, the oral sucker up to ·075 mm. long and ·12 mm. broad, and the acetabulum ·07 by ·095 mm., the latter tending to become nearly as wide as, but shorter than, the oral sucker. In smaller mature worms the dimensions of the suckers are less than those just given. The pharynx may overlap both suckers in very small worms, but in those which are somewhat larger the organ lies above the posterior end of the oral sucker.

The various organs in these strongly contracted worms occupy the same relative position as in relaxed specimens, but the testes (and to a less extent, the ovary) are markedly compressed to become transversely elongate. Eggs in such worms fall within the range found in the more elongate material (30 - 32 μ by 19 - 20 μ).

Our species is closely related to *P. muris* (Tanabe 1922) from rats and mice in Japan. Tanabe's Japanese paper was translated by Dollfus (1925), who reproduced the figures also. Yamaguti (1933, 106) added further details. Hirasawa and Asada (1929, 507) dealt with its life cycle. Olsen 1937, pl. v. 73) republished Dollfus' figure of the adult worm. McMullen (1937a, 113) reported experimental infection of rats, mice, pigeons and man with *P. muris*. The vitelline follicles are indicated in Dollfus' figure as extending a little further forward than in McMullen's (1937 b) figure. Tanabe stated that the intermediate hosts in Japan were *Lymnaea pervia* and Chironomid larvae. McMullen (1937 b, 239) briefly described the species from North American material, as also did Cort and Ameel (1944, 37 - 48). Ishii (1935, 629) in an extensive survey of the rats

(varieties of *Rattus norvegicus*) occurring in the drains and rivers of Tokyo, found four species of trematodes; three of them were echinostomes and the fourth was *Clonorchis sinensis*, but *Plagiorchis muris* was not mentioned.

If Olsen's key (1937) to the species of *Plagiorchis* be used, our parasite would be accommodated beside *P. muris.* The latter was placed by Schulz and Skworzow (1931, 773) in their subgenus, *Multiglandularis,* and Olsen has followed them.

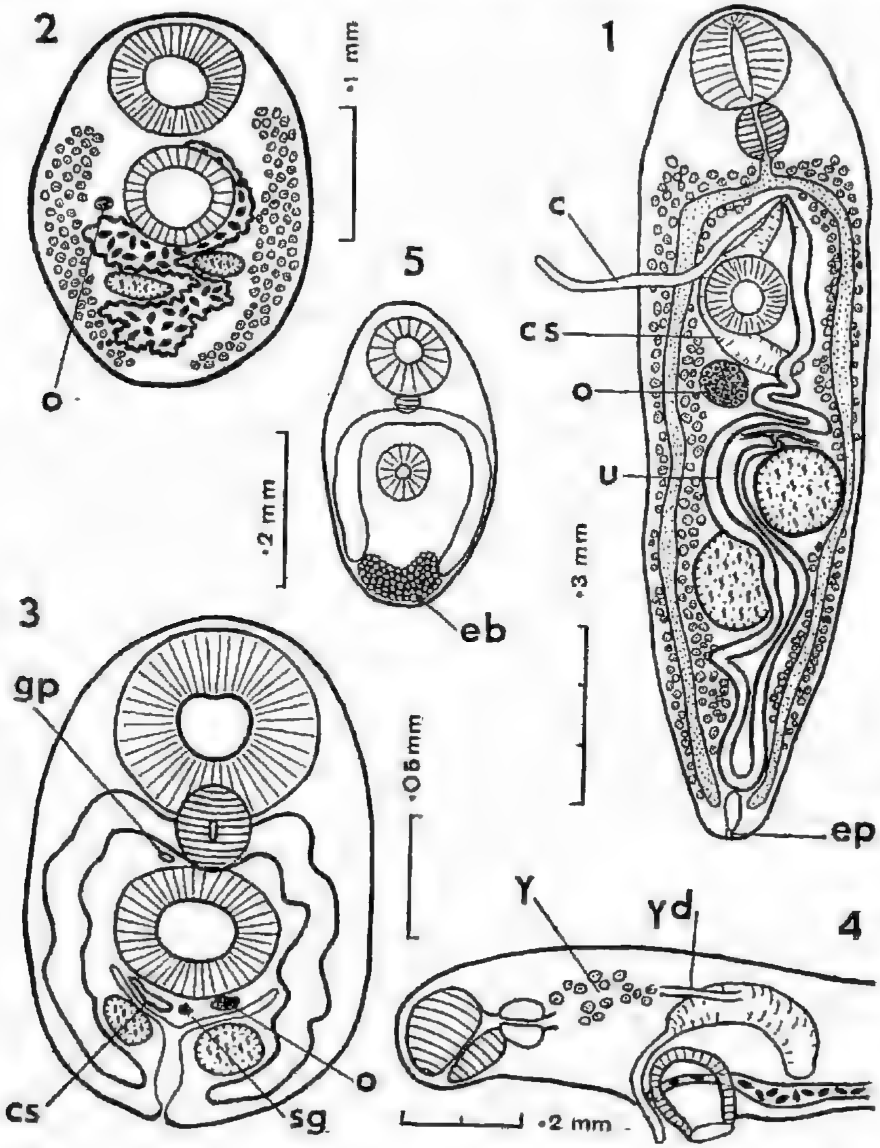

Fig. 1, adult; 2, strongly contracted adult; 3, very young, contracted worm; 4, anterior end, side view; 5, metacercaria, unfixed, somewhat compressed (expressed from a cyst from *Lymnaea lessoni*).

REFERENCE TO LETTERING

al, alimentary caecum; c, cirrus; cs, cirrus sac; eb, excretory bladder; ep, excretory pore; gp, genital pore; o, ovary; ov, probably ovary and shell gland complex; r, refractile granules; sg, shell gland; t1, t2, testes; u, uterus; y, yolk field; yd, vitelline duct.

P. (*M.*) *jaenschi,* in its relaxed condition, differs from *P.* (*M.*) *muris* in the following features: much shorter and narrower dimensions; much smaller oral and ventral suckers, testes and ovary; genital pore close to the intestinal bifurcation; ovary nearer the acetabulum; posterior testes more remote from the end of the worm; and yolk follicles less abundant at the posterior end where the two fields are almost separated.

Experimental Infections

Lymnaea lessoni(1) has been infected with eggs of *Plagiorchis jaenschi* in three separate experiments. The eggs were dissected out from the adult worms and placed in contact with various molluscs, after varying periods. A summary of all experiments performed follows:—

Experiment A. 26/3/47. Eggs (dissected out from a number of adults from Tailem Bend) put in a petri dish containing snails, including 8 *Lymnaeae.* Snails isolated over 24-hour period once a week from eighth week onwards; after 15 weeks one of two surviving *Lymnaeae* emitting large numbers of cercariae. The second snail died in 21 weeks; and although no cercariae had been recovered during the weekly testings, the liver was found to contain many sporocysts and some cercariae which were probably immature. (The six other *Lymnaeae* died after two to nine weeks; none showed sporocysts on dissection.)

Experiment B. 20/12/49. Eggs (Tailem Bend) dissected out and placed on lettuce in dish containing 6 *Lymnaeae* and other snails. The 6 *Lymnaeae* died within 10 days. Sectioning revealed no evidence of development, or even of ingestion of the eggs.

Experiment C. 14/4/50. Eggs teased from 8 adults (Tailem Bend); kept in water for four days, then fed on lettuce to various snails. Of these, the four *Lymnaeae* died in 4, 16, 17 and 21 days; they were dissected carefully, but no signs of infection were noted.

Experiment D. 17/4/50. Eggs from eight adults (Tailem Bend) teased out; kept in water for nine days (26/4/50) before feeding on lettuce to snails. Snails isolated over 24-hour period once per week from 24/5/50. *Lymnaea* (1) emitted cercariae on 14/6/50. (Infection period thus between six and seven weeks.) The three remaining snails were then kept isolated in tubes (being fed on lettuce). *Lymnaea* (2) gave cercariae on 15/6/50; and *Lymnaea* (3) on 21/6/50. *Lymnaea* (4) died on 7/7/50 (*i.e.,* 72 days after infection); on dissection it was found to be harbouring cercariae and a few sporocysts.

Experiment E. 27/4/50. About 18 adults (Bow Hill) were teased up (in the dish in which they had been lying for several days, and which therefore probably contained some naturally laid, *i.e.,* mature, eggs as well). On 4/5/50 the eggs were pipetted on to lettuce in a dish with 6 *Lymnaeae* and other snails. The snails were isolated once per week from 24/5 to 21/6/50, and thereafter examined daily. Three of the *Lymnaeae* became infected; two gave off cercariae after 67 and 74 days respectively, the infection being very light in both cases. The third snail died after 104 days; it had never given off cercariae, but on dissection was found to contain a number of immature sporocysts.

It is believed that infection of the snails occurs by ingestion of the eggs, as is the case with many Plagiorchids. In Experiment D, *Lymnaea* (1) emitted cercariae six to seven weeks after it had been placed in contact with eggs. This is regarded as a comparatively short period for development at this time of the year (April to June). If a free-swimming miracidium were produced, this period would necessarily be shortened.

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(1) The Lymnaeae were known to be uninfected, having been hatched and reared in the laboratory.

According to McMullen (1937 b) Tanabe reported that the fully developed miracidium of *Plagiorchis muris* was produced in 96 hours. Dollfus, 1925, reported that the egg when laid contained an egg-cell and 5 - 6 yolk-cells, and that development of the miracidium was completed in four days at 37°. He did not state whether the miracidium hatched at this time, however. McMullen (1937 b) kept eggs of the American species, from man, at the prevailing August and September temperatures in Michigan, and noted that they did not produce miracidia under 24 days. Our experiments did not show what period after the egg is laid, if any, is required before the miracidium becomes viable.

Other molluscs used in the experiments were *Amerianna* spp., *Planorbis isingi*, and *Notopala hanleyi*. None of these became infected.

C. Plagiorchis jaenschi had not been identified as a natural infection of *Lymnaea lessoni* until April 1949, when it was found in 5 of 45 *Lymnaea*, from Wood's Flat. It was found at Bow Hill in February and April 1950, in 1 of 1,072 and 1 of 460 of the snails, respectively. It has never been recorded from Tailem Bend, where it would not be expected to be a common form, in view of the few *Hydromys* which now frequent the swamps in that region; though cysts, believed to belong to *Plagiorchis jaenschi*, have been found twice in yabbies from Tailem Bend. It should be noted that once or twice we have noted "stylet cercariae" from *Lymnaea*, without further identification; on the other hand, whenever these cercariae were examined more closely, they proved to be a form with stylet 24 μ long. This latter form is the only common xiphidiocercaria found by us in *Lymnaea lessoni*.

The Sporocyst

Sporocysts were present in the livers of the snails in large numbers in the original infection, but less in the later experimental hosts. They are comparatively small, each containing from 2 - 4 cercariae. Average of 7 (not fixed) 645 by 202 μ; range 450 to 825 μ by 150 to 240 μ.

The cells of the sporocyst wall, and the contained cercariae, stained well with a weak solution of basic fuchsin in normal saline. No germ balls were seen; and no details of the excretory system were determined. Tiny green refractile droplets were present throughout the sporocyst wall.

The Cercaria

In general, cercariae emerge from the snail in the early hours of the morning, mostly before 9 a.m. (On one occasion, when no cercariae had been given off earlier in the day, quite a large number emerged between 1 and 2 p.m.)

For the rest of the morning, the cercariae remain suspended in the water, swimming only occasionally. After this they become concentrated at the bottom of the test tube, some of them fastened by the suckers to the tube; sometimes they appear to favour the side nearest the light, but at other times there is no obvious phototactic response. At the end of the day they lie on the bottom of the tube; some of them even attempt to encyst. (It is doubtful whether such encystation preserves their lives, as there was no movement in those "metacercariae" which were removed from the rather ragged, gelatinous coating. Cyst formation was observed several times on the slides—adverse conditions, such as drying out, or perhaps the pressure to which the cercaria was exposed under a coverslip, appearing to stimulate it.) The length of free life may, however, be longer than in many cercariae, for, from the first snail to be infected, a number of cercariae over 48 hours old successfully encysted in *Daphnia* sp.

Measurements of formalinised specimens were subject to some variation, due to the varying states of expansion in which they were fixed. A series of 20 which had been killed at 5 p.m. by adding boiling 10% formalin to an equal

volume of a very weak solution of neutral red, in which they had been placed for ten minutes, ranged from 133 to 187 μ in body length, and from 94 to 148 μ in breadth; the average size being 155 by 120 μ. Ten cercariae similarly treated, but killed at 11 a.m., ranged from 150 to 188 μ in length and 98 to 128 μ in breadth; the average size being 173 by 113 μ. (That is, early in the day the cercariae appear to be fixed in a more extended condition.) The tail measurements are only approximately accurate, due to the fact that the tails were seldom fixed in a perfectly straight condition. They ranged in length from 102 to 162 μ, and in breadth from 26 to 36 μ, an average of 24 specimens (from cercariae fixed in both morning and afternoon) being 132 μ by 29 μ. The measurements of four obviously extended specimens were:—body 255 to 285 μ long and 82 to 90 μ wide (average 270 by 86 μ); tail 158 to 180 μ long and 26 to 32 μ wide (average 172 by 29 μ).

The oral sucker was larger than the ventral, approximate measurements for the former being 41 μ long by 53 μ wide (average of 20 specimens); and for the latter 32 μ long by 38 μ wide (average of 10 specimens).

The stylet (fig. 3) is 34 μ long; 9·5 μ across the widest point, and 6·5 μ across the base. The thickened rim is about 3 μ deep. It does not extend right round the stylet, being incomplete on one face. It starts 10 μ from the tip and from 13 μ the remainder of the "collar" narrows in gradually to a point 15 μ from the base, from which the width remains uniform.

About 20 μ of the length of the tail is enclosed within the body in a caudal pocket which is lined with spines. The pocket may be well retracted into the body, or may be opened out so that the hinder part of its side walls comes to lie on the posterior end of the body. In this region of the pocket the spines, probably about ten on each side, are much longer than elsewhere, and may be seen even in the retracted condition. In the everted position of the pocket they appear as short bristles. After prolonged exposure to a neutral red solution so dilute that it was almost colourless, the walls of the pocket were consistently stained an orange colour, though no other parts of the body were affected by the stain in this dilution.

The general body surface is covered with extremely minute spines which are more prominent anteriorly, and cease to be really obvious at about the acetabular region. Greenish refractile granules, which are mostly fairly large, are more or less evenly distributed throughout the body, except in the region anterior to the pharynx, which is free of them (fig. 7).

There is a mass of gland cells extending from about mid-way between the two suckers to just beyond the posterior border of the acetabulum (fig. 7). Intravitam staining was not of much assistance in determining the number of these cells, which is thought to be at least 10 pairs, and possibly a number more. With neutral red, the three or four large posterior cells show very fine granulation, while the anterior mass takes up the stain quite deeply. The nuclei appear quite clear, and very faintly pink, after basic fuchsin and normal saline. The ducts of the gland cells are often bent upon themselves, or dilated here and there in their course. Some of these, also, show a fine granulation. They run forward together, becoming narrower as they do so, to open near the mouth. Methylene blue stained the cercaria a uniform, very faint, blue, but showed no differentiation at all.

The prepharynx is short and very inconspicuous; the pharynx quite well defined and muscular, but the oesophagus and alimentary crura so inconspicuous that in living specimens there is rarely any indication of their presence. In stained, fixed, specimens they can be distinguished as very narrow structures, one cell in thickness, so that even the existence of a lumen is problematical. The caeca appear to diverge abruptly from the oesophagus.

The excretory system is seen best with the aid of basic fuchsin in normal saline. Cercariae will live all day in good condition for examination in very dilute solutions. Horse serum in addition is also helpful. The posterior part of the Y-shaped excretory bladder opens into the vestibule, from which the excretory pore opens on to the surface of the body. The main excretory tubes open into the cornua of the bladder at the tips, but we had considerable trouble in determining

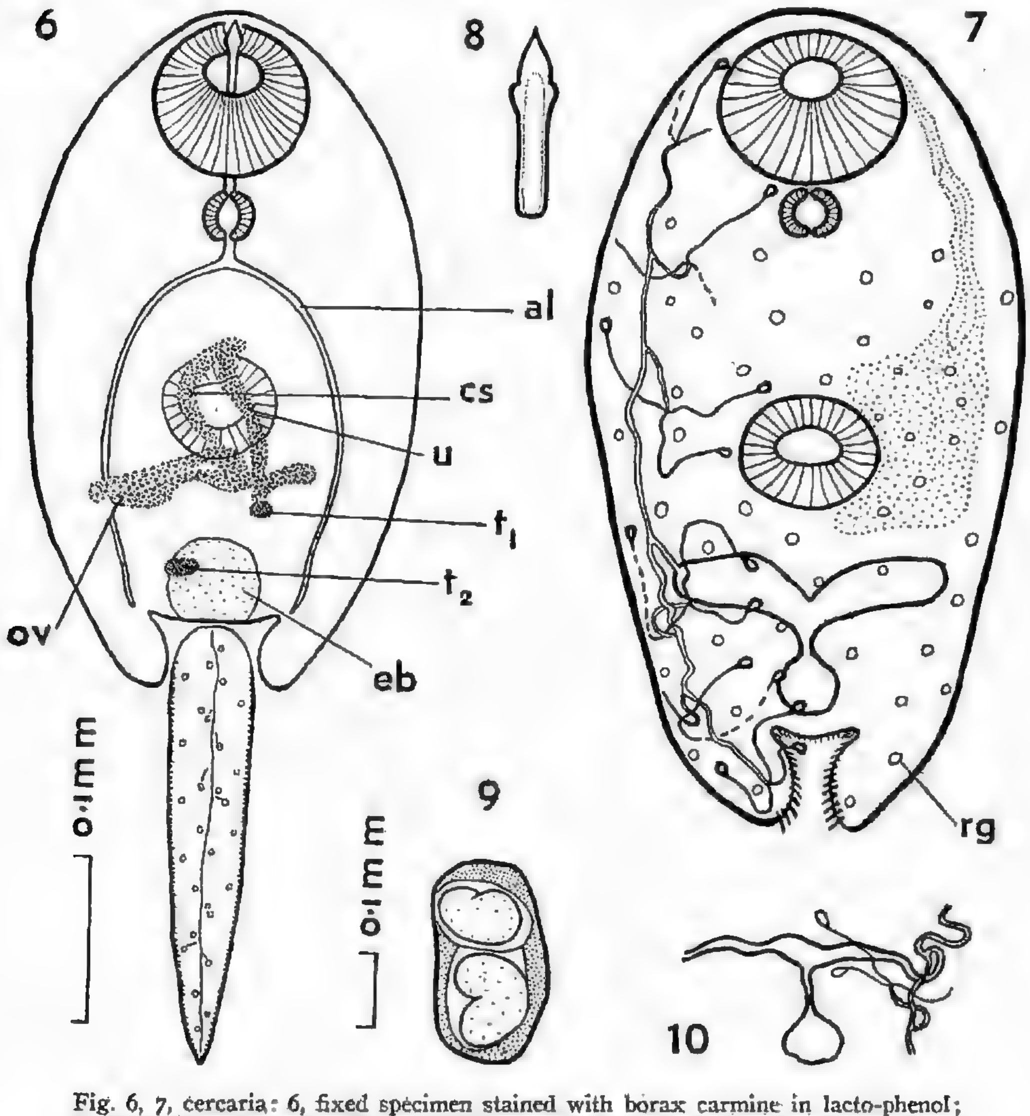

Fig. 6, 7, cercaria: 6, fixed specimen stained with borax carmine in lacto-phenol; 7, details from living specimens. Fig. 8, stylet; 9, two cysts in common envelope; 10, one of the variations in the shape of the bladder.

Fig. 6, 7, to same scale; 8, sketch; 10, sketch.

this because of the presence of cystogenous cells and refractile granules in the area, the twisting of the main and accessory excretory tubes, often over the end of the cornua, and the variability in shape and definition of the arms of the bladder. We mention this to illustrate that in some cercariae, without prolonged study too much reliance cannot be placed on the supposed point of entry of the main excretory tubes.

The canals divide into anterior and posterior collecting tubules at the level of the anterior borders of the excretory bladder. There are three groups of three flame cells connected with each of the anterior and posterior collecting tubules. The excretory formula is thus $2\ (\ (3+3+3)+(3+3+3)\ )$. Although the figure (fig. 7) shows that in some of the groups the whole six elements (three tubules and three flame cells) were not seen in the cercaria, the determination of the excretory formula was made with additional information supplied by a study of a metacercaria seven days old, in which no less than 27 of the 36 flame cells were seen, the positions of these filling in the gaps left in the excretory picture of the cercaria.

The genital primordium consists of a collection of quite undifferentiated cells, but from the relative positions and arrangement of these cells the anlagen of the adult organs can be diagnosed (fig. 6).

The Cyst

The cercariae have been found, experimentally, to encyst in *Daphnia* sp.: the amphipod, *Chiltonia subtenuis;* the yabbie, *Cherax destructor,* and in mosquito larvae; but not in the molluscs, *Amerianna* spp., *Planorbis isingi, Lymnaea lessoni, Plotiopsis tatei* and *Hyridella australis,* or in tadpoles of *Limnodynastes* sp. or the fish, *Gambusia affinis.* In the liver of one of the *Lymnaeae* naturally infected with the cercaria (from Bow Hill) , three cysts which fell within the size range for *Plagiorchis jaenschi,* and contained stylets of the same size, were found; these were obviously cysts of *Plagiorchis jaenschi.* The metacercaria expressed from one of them is figured in fig. 5. McMullen (1937 a, b,) reported that cercariae of *P. muris* and *P. proximus* encysted within the sporocyst. We have not observed this with *P. jaenschi.*

Among the four arthropods, encystation takes place most readily in the yabbie, and this is probably the natural secondary intermediate host, forming, as it does, a large part of the food of *Hydromys.* On at least two occasions (in April 1939 and February 1940) we have found cysts in the gills of yabbies from Tailem Bend. These resemble those of *P. jaenschi* in general appearance and size, and in the site which they occupy.

The cysts were found occasionally in the joint region of the legs, but were predominantly in the main stem of the gills. Sometimes two, three or four were enclosed in series in the same piece of integument, though each had its own cyst wall (fig. 9). The cysts vary in shape from spherical to elliptical. In a series of 15 from the original infection the size range was from 120 by 98 μ to 173 by 158 μ; cysts of the naturally occurring form from Bow Hill ranged from 120 by 98 μ to 210 by 128 μ, and even to 200 by 180 μ in one cyst from a mosquito larva.

The Metacercaria

A metacercaria seven days old was excysted successfully; as mentioned in the description of the cercaria, the excretory formula was thought to be no further advanced. The stylet was still in position in the oral sucker, as it appeared to be in two other cysts of the same age. Metacercariae which were liberated from cysts three months old were relatively small and showed no very great advance in development in those features which could be studied in stained specimens. The genital primordium did not show up even as clearly as in the cercaria, but appeared as a U-shaped string of cells situated in the region dorsal to the acetabulum; this is probably the primordium of the cirrus sac and metraterm. In an average of three stained specimens the oral sucker measured 53 μ long by 68 μ wide, and the acetabulum was 27 μ long by 39 μ wide. We were unable to excyst these metacercariae in sufficiently good condition for studying the excretory system.

In the metacercariae obtained from the host *Lymnaea* (of which, of course, the age is not known) the alimentary system had developed considerably and closely resembled that of the adult. Although the metacercariae were motile, we were unable to determine any excretory detail.

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CRASPEDACUSTA SOWERBYI IN SOUTH AUSTRALIA, WITH SOME NOTES ON ITS HABITS

BY I. M. THOMAS

Summary

1. The occurrence of Craspedacusta sowerbyi Lankester in South Australia is noted and some comments made on its distribution throughout the world.
2. The organisms have been observed to feed on a variety of small Crustacea and also on small mosquito larvae. An increase in rate of pulsation is indicated in the presence of Daphnids but the relation of this to feeding is not proven.
3. Medusae show no response to incident light.
4. Medusae show a marked contraction of the velum at low temperatures and are incapable of swimming movements at temperatures below about 13ºC.

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By I. M. Thomas *

[Read October 12 1950]

SUMMARY

1. The occurrence of *Craspedacusta sowerbyi* Lankester in South Australia is noted and some comments made on its distribution throughout the world.
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The genus of freshwater medusae, *Craspedacusta*, is now known to be widely distributed throughout the world. It was first described from specimens taken in the *Victoria regia* tanks in Regent's Park, London, in 1880 by Lankester (1880). It has since been recorded from other parts of England, Europe, North America, Eastern Asia and now an occurrence has been recorded from Australia (Thomas, 1950).

Several species have been described but the validity of some of them is now in doubt. *C. (Limnocodium) sowerbyi* was established by Lankester from material in Regent's Park, while *C. ryderi* which has been found in some eighteen of the States of North America is now, according to Boulenger and Flower (1928), believed to be identical with it. *C. kawaii* was described from material in the Yangtse River in China by Oka (1907), but it is likely that this (Tang, Yang and Fang (1936)) is only a variety of *C. sowerbyi*. *C. germanica* was described by Persch (1933), mainly from the hydroid stage, but this again seems to be synonymous with *C. sowerbyi* (Boulenger and Flower 1928). *C. iseana* described from material found in a well in the province of Ise in Japan by Oka (1922) does differ in sufficient detail, *e.g.*, smaller total number of tentacles, absence of ring canal, position of the lithocysts at the bases of the tentacles and the isolated arrangement of the nematocysts, to justify its separation.

It seems that the other three species, viz., *C. sowerbyi*, *C. kawaii*, and *C. germanica* may be resolved into the single species *C. sowerbyi*. If this is the case, its occurrence on four of the world's five continents is remarkable. Furthermore, the localities in which it has been found in various parts of the world calls for comment. Of some twenty-nine occurrences in the United States between 1932 and 1938 (Schmitt (1938)), nineteen were in artificial waters such as garden ponds, tanks, aquaria, gravel and clay pits and reservoirs. More recently, Dexter, Surrarrer and Davis (1949) have recorded the medusa from the States of Ohio and Pennsylvania. Some eighteen records are mentioned of which only six are from natural expanses of water, one being a slow flowing stream. In Great Britain and on the Continent, all its occurrences have been in artificial bodies of water (*e.g.*, Tattersall (1933) and

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van Someren (1933), though Totton (1929) believes that it is "highly probable that *Craspedacusta* occurs in a wild state in British river systems." There is no direct evidence of this as yet however. In Eastern Asia, apart from *C. kawaii*, which is widespread in the Yangtse and its tributaries, all its appearances have been in similar locations. The single Australian record is from an excavated reservoir. (Thomas 1950).

The predominances of occurrences in artificial waters may have two possible explanations. It may be that such localities are more frequently and more closely observed so that the short-lived medusae would be more likely to be noted when they appear, or it may be that artificial ponds and the like are more frequently stocked with vegetation from other sources thus introducing the hydroid form in mud containing frustules. In at least one case, importation can be attributed to this cause. Amemiya (1930) noted the sudden appearance of medusae in his laboratory aquarium in Tokyo not long after he had introduced into his tanks some water plants imported from San Francisco. In most cases, however, the medusa appears suddenly in fairly large numbers in waters where there is no record of the recent introduction of new plants or animals. The hydroid stage is capable of reproducing asexually by transverse fission, frustule formation, and bud formation (Persch, 1933) and can presumably remain viable in these forms for long periods, medusae being produced only when conditions are favourable. Once the latter have appeared, most records show that their production is repeated annually at about the same season for some years.

There is little direct evidence of the ability of the hydroid or its frustules to resist desiccation. Their formation has been described in detail by Persch (1933) but he does not mention any form of encapsulation. Payne (1924), however, states that the hydroid bears a covering which is "more than a slimy mucous secretion" and figures it as having a layered structure. Mud and detritus particles adhere to this. Frustules may be able to develop a similar protection. Dissemination of the organism must then be in mud carried on the roots of transplanted vegetation or possibly on the feet of water birds.

The natural centres of occurrence of *Craspedacusta* seem to be North America and the Yangtse, and from these sources it has been conveyed by natural or artificial means to other parts of the world. It is impossible to say at present with any degree of certainty from which of these regions the forms found at Thorndon Park Reservoir near Adelaide emanated. There is no evidence of either plants or animals having been deliberately introduced since the opening of the reservoir ninety years ago though some English perch have become established there, probably having come from entering streams or from other reservoirs which now feed into Thorndon Park. The reservoir has now no significant natural inflow but it is maintained as a storage tank being filled by gravity from other reservoirs higher in the hills behind it. Investigations have failed to disclose the presence of medusae in these even though there is a weekly routine examination by officers of the Engineering and Water Supply Department.

The first specimens were seen on March 7th, 1950, and several visits in succeeding months showed their presence in varying numbers up until June, since when none have been seen. The numbers of specimens taken on different dates in this period are indicated in Fig. 1. The points marked cannot be regarded as being more than a rough indication of the number of organisms present as weather conditions influence considerably the ease with which they can be seen in the water. An overcast sky and a moderate breeze ruffling the surface make their observation more difficult. All visits were made in the early afternoon. Specimens were caught with a hand net from

a boat. Approximately an hour was spent on the lake on each occasion. There appears to be a marked peak in abundance at about the end of April and the beginning of May, the surface water at this time being between 16° and 17°C. All medusae taken were female. Their gonads ripened at about this peak period of abundance. Medusae caught varied in size between 1cm. and 1·9cm., the larger specimens being taken at the period of peak abundance.

Medusae were always found most abundantly in about the centre of the lake, where the depth is thirty feet or more. On no occasions were they seen towards the sides in less than ten or twelve feet of water. Even when fairly strong breezes caused appreciable surface currents, still no specimens were

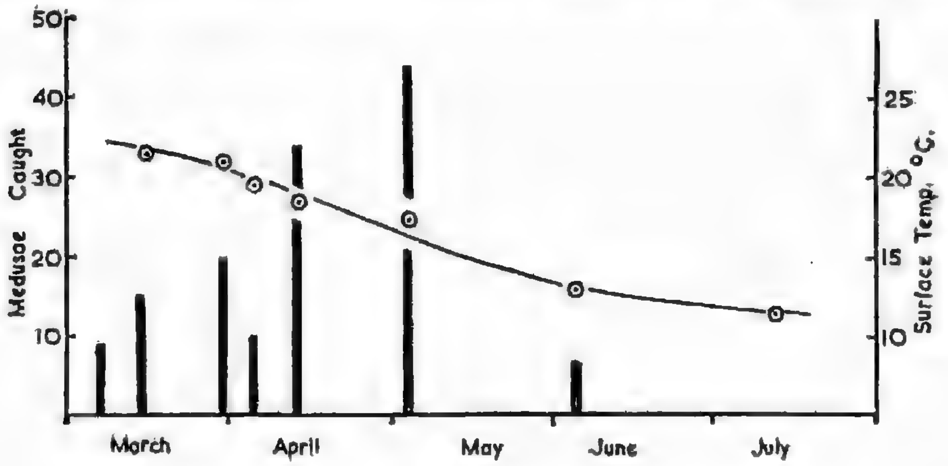

Fig. 1
Heavy vertical lines indicate the abundance of *Craspedacusta* at different dates. Points show surface water temperatures on those dates.

seen near the leeward bank. Generally they occurred in loose patches of about half a dozen individuals in several square yards, this being separated by ten or fifteen yards from another similar patch. Their numbers were thus considerably less than have been reported from several locations in North America where, for example, Cheatum (1934) records that in a small artificial pond near Dallas, Texas, a single scoop with a pint jar yielded as many as sixteen specimens. Sufficient were brought back from Thorndon Park to the laboratory from time to time to allow of some detailed observations on their habits and to carry out some experiments.

FEEDING

Specimens in the laboratory have been observed to feed on Daphnids, Cyprids, small Amphipods and first and second instar mosquito larvae. Daphnids were the commonest food and indeed the only type of food observed in the gastrovascular cavity of those in the reservoir. If some of these were placed in a finger bowl with a medusa, many of them were killed, presumably by coming into contact with the nematocysts of the tentacles. Death was by no means instantaneous because many escaped after being entangled with a tentacle. Further, food organisms could be seen to be still motile after entering the gastrovascular cavity. The mouth is four-cornered and that part of the gut enclosed in the manubrium is transversely ridged in such a way that when the manubrium lengthens and shortens with each pulsation of the bell, the food is forced further in. Once in the more spacious gastrovascular

cavity, the particle can float around more freely in the fluid it contains and it may even penetrate not only into the base of a radial canal but also into the lumen of a gonadial sac.

The tentacles were not observed to play an active part in the passing of food to the manubrium but by unilateral contractions of the velum and a simultaneous flexing of the manubrium in that direction, the mouth could be brought close to the tentacles. No passage of food in this way was ever observed however.

To test the activity of the animals in the presence and absence of suitable food, the following experiment was performed. Four medusae of about equal size were placed in finger bowls each with 200ml. of water. Their temperatures were maintained at 18°C. Rates of pulsation were noted at intervals over a period of half an hour. Then to each of the first two bowls were added 10ml. of water at the same temperature and to each of the second two, the same quantity containing ten living Daphnids. Rates of pulsation were again noted in the succeeding half hour. The results are summarized in Table I. There is a mean difference of 9·1 pulsations per minute with added Daphnids and 0·8 in the controls. This indicates that the presence of Daphnids does stimulate the medusae to greater activity, but further experiments would be necessary to prove the matter conclusively.

Table 1

Averaged Rates of Pulsation, each taken from ten readings, of Medusae in the Absence and Presence of Living Daphnids.

Medusa No.	1	2	3	4
Control Period	85·0	86·8	82·4	84·8
Water only added	84·4	85·8	—	—
Daphnids added	—	—	93·3	92·1
Differences	0·6	1·0	10·9	7·3

It has been observed frequently that when a medusa strikes against a solid object such as floating vegetation, or the bottom or sides of a jar, the rate of pulsation increases. Swimming Daphnids may offer a similar stimulus to more rapid pulsation, though whether this possible increase is of any significance in feeding has not been determined by the experiment described nor by replicates of it as on no occasion were Daphnids taken into the mouth though many were killed by contact with the tentacles. The increase in rate of pulsation when a medusa comes in contact with a solid object as, for example, submerged vegetation, was observed and commented upon by Milne (1938), who says that this increase in activity frequently served to push the object to one side so that the organism could force its way past. The present writer has frequently observed the same phenomenon. Once the obstruction was passed, pulsation rate fell to a more normal level.

REACTION OF LIGHT

Milne (1938) reports, as a result of observations on *Craspedacusta* taken at Crystal Lake, near Lynchburg, Virginia, that they have no apparent reaction to incident light. Shadle and Minthorn (1939) on the other hand say that when they found the medusae in a large pond in a gravel pit near Attica, N.Y., they were more frequent in the shadow of a pier. Cheatum (1934) reports finding the medusae most abundantly under lily-pads and in the "ooze" at the bottom of a shallow pond near Dallas. He states, "Wading amongst the lily-pads stirred up the "ooze" on the bottom and in areas where medusae

had not hitherto been visible, such riling of the water caused them to appear in thousands." Tang, Yang and Fang (1936), contrary to these findings, report on a positive response to sunlight and electric light but found no response to moonlight.

To check these findings, some medusae were placed in a long glass tube about one and a half inches in diameter, filled with water and arranged horizontally so that light could impinge on the organisms from either or both ends. The experiment was of course carried out in an otherwise dark room. The medusae, though quite active during the experiment, showed no reaction at all to the direction of the light. Similarly when the tube was arranged vertically, there was no apparent response. The use of red, yellow, green and blue filters showed them to be equally unresponsive to any particular range of the spectrum. The experiment was repeated with medusae which had been kept in complete darkness for five hours. After this treatment they were slightly less active but still evinced no response.

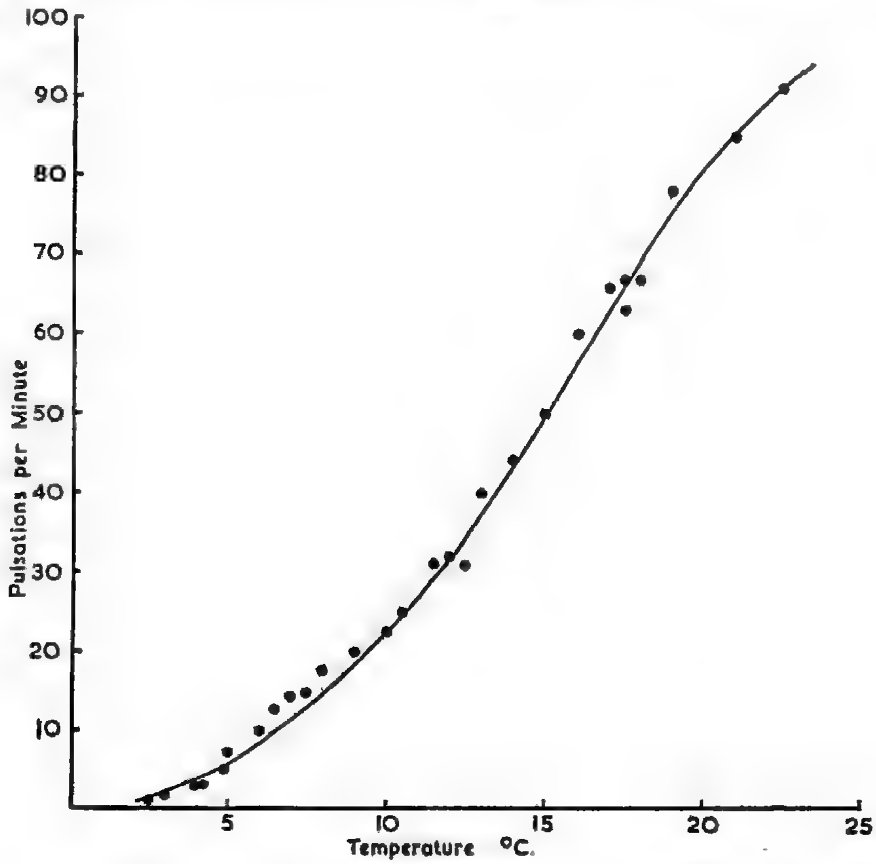

Fig. 2
Influence of temperature on the rate of pulsation in *Craspedacusta.*

REACTION TO TEMPERATURE CHANGES

To test the responses of a medusa to lowered environmental temperatures a specimen was placed in a finger bowl of water and then placed in a larger basin containing water to which chipped ice could be added. The temperature was reduced slowly after the organism had become acclimatised for several hours at 22·5°C. The results are shown in Fig. II. It has already

been noted that the medusae increase their rate of pulsation when they strike against a solid object. Points in the figure indicate, for the higher temperatures, rates of pulsations in free floating specimens. As the temperature fell, contraction of the velum became more strongly marked until at below about 14·5°C. the animal ceased to swim and sank to the bottom, where it continued slower and more feeble movements as the temperature fell still lower. Below 5° C. the animal was almost spherical, only a small round aperture remaining in the velum. The manubrium was completely retracted within the sub-umbrellar cavity. Slight pulsations were maintained at a very slow rate down to 2·5°C.

The temperature was allowed to rise gradually after about fifteen minutes at this level and as it did so, pulsations became more frequent and stronger. At 10°C. the velum was reasonably relaxed but it was not until between 14° and 14·5°C. had been reached that normal swimming movements were recommenced. It is interesting to note that the medusae disappeared from the surface waters of Thorndon Park Reservoir when the surface water temperature fell below 13°C. (see Fig. 1). If any remained in the reservoir at that date they were presumably at or near the bottom. The difference in temperatures of cessation of normal swimming in the reservoir and under experimental conditions, can be attributed to acclimatisation of the former to lower temperatures.

The upper limit of temperature tolerance has not been determined here but Milne (loc. cit.), gives it as between 25° and 30°C. for his specimens. Specimens investigated by Tang, Yang and Fang (1936), in Amoy, showed a temperature preference of 28°C., which was approximately the normal ambient temperature.

They say that, in a long tube, the medusae moved from cooler and warmer regions and congregated at this temperature. When cooled in beakers from 28°C. movement became abnormal at 31° to 35°C. and ceased at 36°. At 28°C. the rate of pulsation was about 120 per minute. The higher temperatures tolerated by these specimens can be accounted for by their acclimatisation to a high environmental temperature.

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ADDENDUM

Since this paper went to press, a reprint of an article by P. L. Kramp ("Freshwater Medusae in China", Proc. Zool. Soc. Lond., **120**, 165-184, 1949) has been received. In this, the distribution of *C. sowerbyi* in China is discussed and details given of a further species, *C. sinensis*, first described by Gaw and Kung (Sci. Rep. Nat. Wuhan Univ., pp. 1-11, 1939). This co-exists with *C. sowerbyi* in pools near Kaitung, Szechuen, though it is much less abundant. Kramp supports the contention of Sowerby (1941) that the Upper and Middle Yangtse River Valley is the original home of the genus, whence it has been transported probably by human agency to other parts of the world, possibly in mud on the roots of the water hyacinth (*Eichhornia*) or similar water plants.

Eichhornia has been introduced into Australia, and bade fair to become a serious pest in the River Murray and other places until vigorous measures were taken to control it. It has not, however, been reported from any of the Adelaide reservoirs though it is still fairly common as a garden plant on the Adelaide Plains. The Adelaide Hills region, which includes the drainage area of the reservoirs, does not offer a suitable habitat for the growth of *Eichhornia*, so it does not seem likely that this plant is the medium through which the coelenterate was introduced into Australia.

Up to the present time (June 1951) no further specimens of the medusae have been reported from the Adelaide reservoirs.

THE MORPHOLOGY AND LIFE CYCLE OF THE TREMATODE, APATEMON INTERMEDIUS, FROM THE BLACK SWAN

BY T. HARVEY JOHNSTON AND L. MADELINE ANGEL

Summary

1. The anatomy of the trematode, Apatemon intermedius (S. J. Johnston) from the duodenum of the black swan, is described.
2. Hatching time of the eggs is about 33 days in early summer.
3. Cercaria lessoni, from the pulmonate molluscs Lymnaea lessoni, Simlimnea subaquatilis, and Planorbis isingi, is its larva. Cercariae may be produced within 35 days of invasion of the miracidium.
4. The second intermediate hosts are freshwater leeches, Glossiphonia spp., in whose bllod vascular system the encysted tetracotyle occurs.
5. 23-day-old metacercariae are compared with those of Cercaria burti Miller 1923 (Stunkard, Willey and Rabinowitz 1941). In A. intermedius they are encysted at this stage.
6. Juvenile stages found in the black swan are described.
7. Two strains of A. intermedius, infecting respectively Planorbis isingi and Lymnaea lessoni, are postulated.
8. In view of the wide separation between the reported types of snail host for A gracilis, viz., Bithynia (Szidat) and pulmonates (Stunkard et al.) in Europe and North America respectively, we regard it as likely that two distinct species are involved.

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By T. Harvey Johnston and L. Madeline Angel*

[Read 9 November 1950]

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4. The second intermediate hosts are freshwater leeches, *Glossiphonia* spp., in whose blood vascular system the encysted tetracotyle occurs.
5. 23-day-old metacercariae are compared with those of *Cercaria burti* Miller 1923 (Stunkard, Willey and Rabinowitz 1941). In *A. intermedius* they are encysted at this stage.
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The Adult

The Strigeid trematode, *Apatemon intermedius*, was described as *Hemistomum intermedium* by S. J. Johnston (1904, 109-110), whose material came from the duodenum of the black swan, *Chenopis atrata*, Lath., from the Duckmaloi River, New South Wales. Although the author placed the species under *Hemistomum*, he stated that the fusion of the lateral expansions of the body wall in the posterior region of the fore-body, together with the form of the "clinging apparatus," approached the condition occurring in *Holostomum* (*i.e., Strigea* and allied genera). Dubois transferred it to *Apatemon* (1937a, 392; 1937b, 232), gave a summary (1938, 105) of the short original account, and reproduced one of Johnston's figures.

Attempts to trace S. J. Johnston's material in the Technological Museum, Sydney, where he was at the time Economic Zoologist, and in the Zoology Department of the University of Sydney, where he later became Professor, failed to locate it. Though the Australian Museum received types of most of his later species of trematodes, his *H. intermedium* was not included.

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We have found *A. intermedius* in five of eleven black swans taken from the Murray River swamps at Tailem Bend, South Australia, during the summer months between October 1939 and April 1947; and in one collected at Bow Hilll, north of Mannum, in May 1950. The worms were obtained from the duodenum and, on one occasion, from the proventriculus. Usually only a few were present in infected birds, but on one occasion, in October 1947, abundant very young stages, with adults, were obtained from the duodenum.

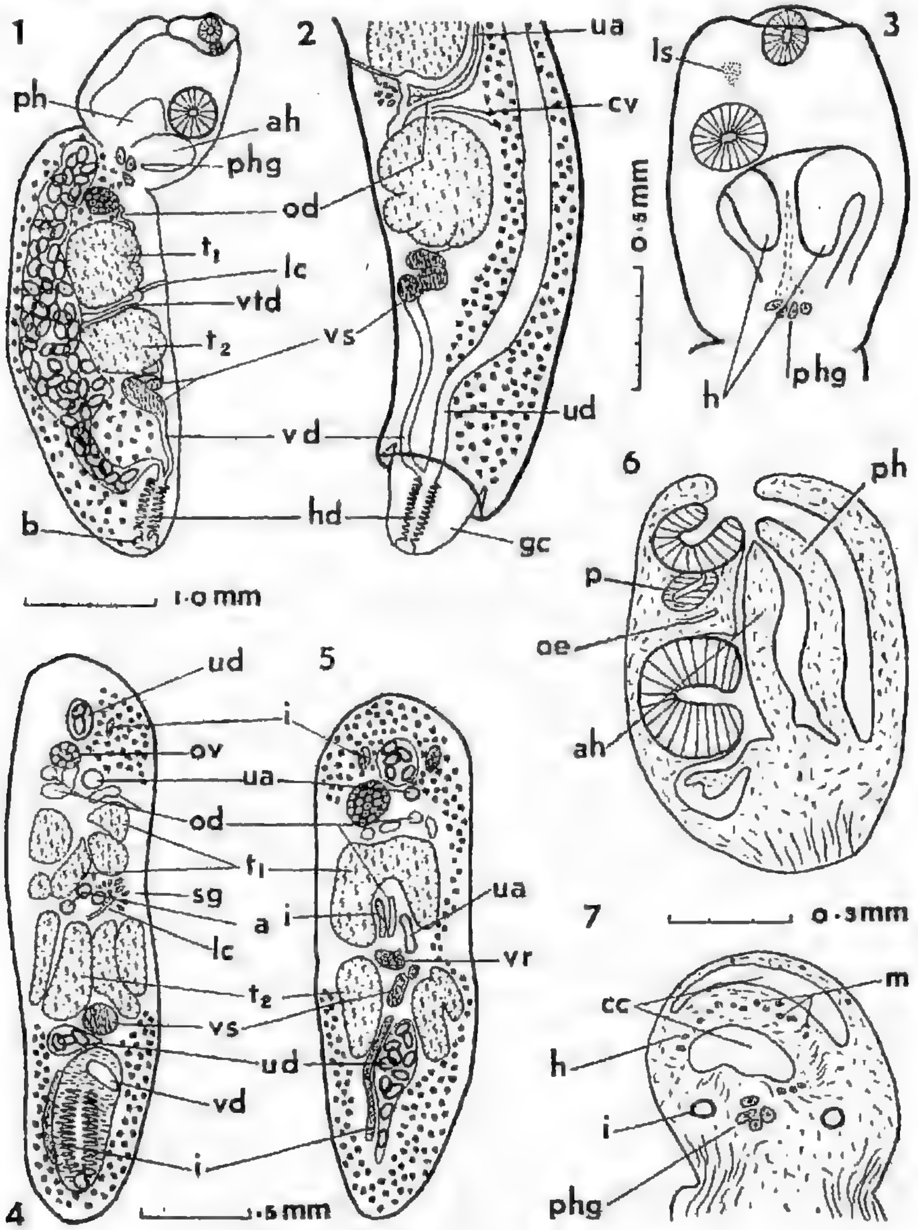

Fig. 1-7

Apatemon intermedius, adult: 1, lateral view; the vitellaria covering the testes laterally have been omitted. 2, posterior region, ventral, bursa everted. 3, fore-body, ventral. 4, 5, L.H.S. hind-body; fig. 5 represents a section more ventral than that shown in fig. 4. 6, L.V.S., fore-body. 7, oblique L.V.S., showing base of fore-body. Fig. 2 and 3 to same scale; 4 and 5; 6 and 7.

Since most adult specimens have the fore-body more or less bent back on the dorsal region of the hind-body, the neck occupies an oblique position and the dorsal and ventral surfaces of the hind-body are of unequal length. In such cases, whether adult or juvenile, the length of the fore-body has been taken as the distance between its anterior end and the middle of the neck, just behind the prominent group of glands lying behind the holdfast apparatus. The length of the hind-body is the distance between the above-mentioned point in the neck and the posterior end of the worm (with its bursa retracted). The total length of the trematode is the sum of the two measurements. All specimens were measured in glycerine or in cedar wood oil, and without coverglass or pressure, unless otherwise stated.

The fore-body was usually strongly bent back towards the dorsal part of the hind-body. Egg-bearing worms were from 3·5 to 5 mm. in length, the fore-body being 1 to 1·5 mm. long, ·9 to 1·25 mm. in maximum diameter, approximately circular in transverse section, and with its sides not quite parallel. There is a definite neck constriction. The hind-body is subcylindrical, narrowing somewhat towards each end, and its ventral surface tends to form a low arch. The posterior extremity is directed slightly dorsally and is broadly rounded when the genital papilla is withdrawn within the bursa.

The maximum widths of the fore- and hind-body are usually about the same, but there is some variation in this respect. The hind-body varied from 2·5 to 3 mm. in length and ·75 to 1·5 mm. (usually 1 – 1·25 mm.) in maximum breadth. The ratio of the length of the fore- and hind-body was about 1 : 2·2 – 2·5. The smallest egg-bearing worm, the dimensions of which have not been included in the foregoing measurements, was only 2·75 mm. in length, with a fore-body 1·0 mm. long and ·9 mm. wide, and with a narrow hind-body 1·75 mm. long and ·8 mm. in maximum breadth: the ratio of fore- to hind-body is thus 1 : 1·75. S. J. Johnston reported the following lengths:—entire worm 3·6, fore-body 0·67, and hind-body 2·93 mm., the ratio thus being about 1 : 4·4; but if we apply our method of measurement to his figure 7 (which is × 37), the total length of the specimen figured would be about 2·7 mm., that of its fore-body ·76 mm., and that of its hind-body 1·94 mm., giving a ratio of 1 : 2·5 as in our adult material.

The genital papilla, when fully protruded, is a large cone with a rounded tip, this cone measuring ·3 to ·5 mm. in length, thus being about one-tenth the total length of the worm.

The oral sucker, ·15 – ·22 mm. in diameter, is subterminal; the ventral sucker is larger, ·3 – ·33 mm. in diameter, and sometimes is stalked. The latter, when not stalked, reaches almost to the dorsal surface. The relative positions of the two suckers is indicated in the figures. The sucker ratio varies from 1 : 2 to 2 : 3. Lying laterally in the region between the two suckers, and on a level with the oesophagus and part of the pharynx, are the lateral suckers. When studied in serial sections each is seen to be an extensive wide depression lined by muscle fibres which pass to other parts of the fore-body. Unlike true suckers, they do not possess a definite basement membrane so that their inner boundary is not sharply delimited. They are obviously the persistent lateral depressions of the tetracotyle. S. J. Johnston referred to (and figured) two groups of very large unicellular glands, each group opening into a crescentic depression of the ventral body surface. We have not been able to recognise such gland cells in our material.

The cup within the fore-body is very extensive, its anterior border reaching usually almost to the posterior end of the anterior sucker. S. J. Johnston seems to have missed its anterior margin, judging from his remarks and his figure 8; but his figure 7 indicates the condition more nearly, though we have

not often seen such a markedly petiolate acetabulum as he indicated in fig. 7. Projecting from the base of the cavity behind the ventral sucker, are two large complexly folded "clinging plugs" or tribocytic organs. The more posterior may be the longer, and may project slightly through the mouth of the cup. Both organs may have their margins infolded or even rolled back on their more basal portions. The anterior of these organs is grooved longi-

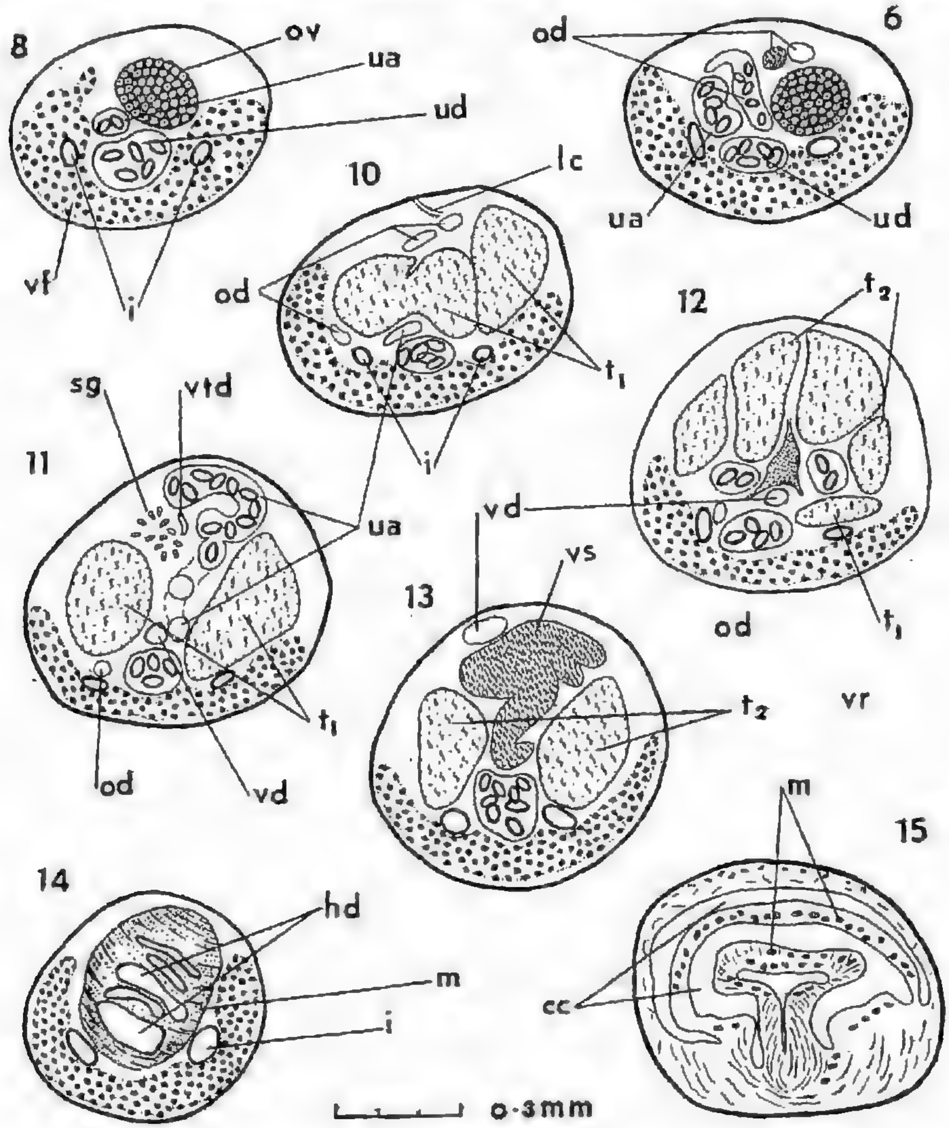

Fig. 8-15

Apatemon intermedius, T.S. hind-body of adult: 8, at level of ovary, showing caeca surrounded by vitellaria; ascending uterus about to join descending limb. 9, at level of ovary and coils of oviduct. 10, at level of anterior testis; Laurer's canal; oviduct passing upwards laterally from testis to occupy dorsal position. 11, at level of posterior part of anterior testis; ascending uterine coils moving into more ventral position between testicular lobes. 12, at level of posterior testis, showing its marked lobulation; two vitelline ducts, reservoir and common vitelline duct. 13, at level of posterior part of second testis; vesicula seminalis lying dorsally between testicular lobes. 14, through hind-body in region of hermaphrodite duct and retracted bursa. 15, through posterior region of head, showing bases of holdfast organs.

tudinally and transversely when withdrawn, and its stalk appears to have a glandular base and core. The musculature of these organs is strongly developed, the bundles of fibres being large, numerous and deeply staining. Behind these organs is a very striking group of large unicellular glands. spherical or pyriform, but the actual openings into the base of the cup were not recognized. The cytoplasm of the glands contained numerous small vacuoles which may perhaps represent the position of secretory granules in the living cells. S. J. Johnston did not mention these organs which, in unstained worms, appear as a small group of large highly refracting bodies between the base of the tribocytic apparatus and the neck of the worm. Dubois (1938, fig. 45 - 46), as well as Stunkard, Willey and Rabinowitz (1941, pl. 1, fig. 6) indicated the presence of similar structures in *Apatemon gracilis*. The hind portion of the fore-body is well supplied with longitudinal muscle fibres, which extend from the walls of the cup and from the base of the tribocytic apparatus into the body wall of the hind-body.

The oral sucker faces almost ventrally. It is succeeded by a pharynx ·08 – ·13 mm. long by ·05 – ·07 mm. wide, which is directed postero-dorsally. There is no prepharynx. The oesophagus bends ventrally in the region in front of the acetabulum, where it divides into the two crura which pass back, one on either side of the acetabulum, the two tubes approximating as they pass through the neck. In the hind-body they lie in the ventral region, below the testes and on either side of the descending uterus. In the most anterior part of the hind-body, just behind the neck, and even in part of the ovarian region, they are actually surrounded by the inner vitelline follicles, but elsewhere they lie just dorsally from the neighbouring yolk glands. The crura terminate near the posterior end of the worm and lie beside the retracted genital papilla.

The testes are large and are arranged in tandem. They are very deeply lobed, and in longitudinal and transverse sections may each appear to consist of four or five separate organs. The testes lie dorsally to the vitelline region, the caeca and the descending uterus, but ventrally to part of the ascending uterus and the shell glands. The anterior testis is about ·7 mm. long and ·6 mm. in dorsoventral diameter; the posterior testis, ·5 by ·6 mm. The testicular region occupies about 1·2 mm. in length in a worm 4·3 mm. long with a hind-body 3 mm. in length. This zone is about one quarter of the total length of the worm. The anterior margin of the anterior testis is distant from the neck about one-sixth the length of the hind-body, while the posterior end of the hind testis is distant from the end of the worm (with retracted bursa) nearly one half the length of the hind-body. The anterior vas efferens arises ventrally and travels back above the descending uterus to join the posterior vas efferens immediately behind the second testis. Here it forms the voluminous, twisted vesicula seminalis which occupies a dorsal zone behind the testes and above the uterus. Eventually it becomes the vas deferens which is joined by the uterus from below, and the wide strongly folded hermaphrodite duct so formed enters the tissues of the genital cone. The latter when retracted lies within the bursa copulatrix whose wide aperture is slightly dorsally directed. As in other species of *Apatemon* there is no well-marked bursal sphincter. The cone when fully protruded may measure ·3 to ·5 mm. in length.

The spherical ovary is about ·2 mm. in diameter and is situated on one side at about the mid-dorsoventral level, close behind the neck constriction. Its posterior border may touch the anterior testis. Between the latter organ and the ovary, and occupying a region on the anti-ovarian side, is the wide oviduct. The latter arises from the ovary just above the uterus, and then makes its way dorsally to become arranged in a number of coils in the pos-

terior ovarian region, and especially in the region immediately in front of the anterior testis, some of the coils lying above portions of the latter. It then comes to occupy a more ventro-lateral position, below the anterior testis and on one side of the descending uterus. From here it makes its way dorsally just laterally from the end of the anterior testis, and in the narrow intertesticular region, it enters the shell gland and unites with the common yolk duct. From this point arises the narrow Laurer's canal which passes dorsally in a curved course to reach the surface above the posterior part of the anterior testis. The ascending uterus becomes thrown into a number of loops between the lobes of the anterior testis, and makes its way ventrally and forwards so as to lie just above the descending uterus and partly amonst the loops of the oviduct. Inwardly and ventrally from the ovary, the two parts of the uterus lie side by side, the descending limb being the more ventral, and in the region between the ovary and the anterior extremity of the hind-body, the ascending uterus bends down to continue back as the descending uterus. The latter occupies a median position below the testes and seminal vesicle and between the intestinal crura, but above the neighbouring vitelline glands. It eventually enters the hermaphrodite duct midventrally, while the vas deferens enters it dorsally and laterally. The hermaphrodite duct, when the bursa is withdrawn, is strongly contracted, its walls being thrown into a great number of closely arranged folds surrounded by loose tissue and muscle fibres, the whole organ terminating at the genital cone.

The yolk glands are very extensive and occupy a ventral and ventro-lateral zone extending from the neck to the posterior end of the hind-body. At either end of the latter the follicles tend to extend rather more towards the dorsal surface than they do elsewhere. As already mentioned, the vitellaria surround the crura in the pre-ovarian region. The two short main yolk ducts pass inwards and upwards in the intertesticular zone, the uterus lying between them. The two ducts soon join to form a small, more or less triangular, yolk receptacle from which there issues directly dorsally the tubular common yolk duct. The latter joins the widened oviduct near the dorsal surface. The shell glands lie between the posterior lobes of the anterior testis. Laurer's canal has already been mentioned.

An examination of S. J. Johnston's figure (pl. 5, fig. 7) indicates that the fore-body has been cut nearly sagitally, and the hind-body mainly longitudinally and horizontally. As the figure shows the two crura cut longitudinally, we would expect to see a mass of yolk glands on both sides of the posterior end of the hind-body, because of the relation of the crura to the vitelline region.

Eggs are ·072 to ·09 by ·062 - ·065 mm., showing very little variation in form and size, most of them being ·087 by ·062 - ·065 mm. They were not mentioned by S. J. Johnston.

A. intermedius seems to be nearest to *A. gracilis* (Rud.) Szidat, as figured by Dubois (1938, fig. 45-46), but is differentiated from it by having a larger size; a more forward position of the testicular region, the ovary, and the anterior end of the uterus; a much longer hermaphrodite duct; a relatively longer genital cone; and by the different sizes of the eggs. *A. gracilis* occurs in Europe as an adult in ducks; as a cercaria in *Bithynia tentaculata*, and as a tetracotyle in freshwater leeches, *Herpobdella* and *Haemopis* (Szidat 1931, 160-172; 1929, 728-730; Neveu-Lemaire 1936, 248).

Szidat (1931) reported that the larva of *A. gracilis* closely resembled, but was specifically distinct from, *Cercaria burti* Miller, and gave tabulated measurements of the two larvae (p. 165). The North American hosts of *C. burti* were *Planorbis trivolvis* (Miller 1926, 41-44), *Lymnaea stagnalis* (Miller 1927, 77), and *Lymnaea humilis* (Cort and Brooks 1928, 209-210). Willey and Rabinowitz

(1938) stated that *C. burti* had its metacercarial stage in leeches (*Herpobdella* sp.) and tentatively assigned the adult (obtained from ducks after experimental feeding of cysts) to *Apatemon sphaerocephalus.* Olivier (1940) listed *C. burti* as the larva of *A. globiceps,* giving as reference Willey and Rabinowitz's paper of 1938; but in 1941, with Cort and Brackett (Cort, Olivier and Brackett 1941, 440) he listed *C. burti* as the larva of *A. sphaerocephalus.* *A. globiceps* was a renaming by Dubois (1937, 392; 1938, 100) of *A. sphaerocephalus* (Brandes) Szidat, nec Westrumb, the latter's species being a *Strigea.* Stunkard, Willey and Rabinowitz (1941) regarded *C. burti* as the larva of *A. gracilis,* with *C. pseudoburti* Rankin 1939 as a synonym.

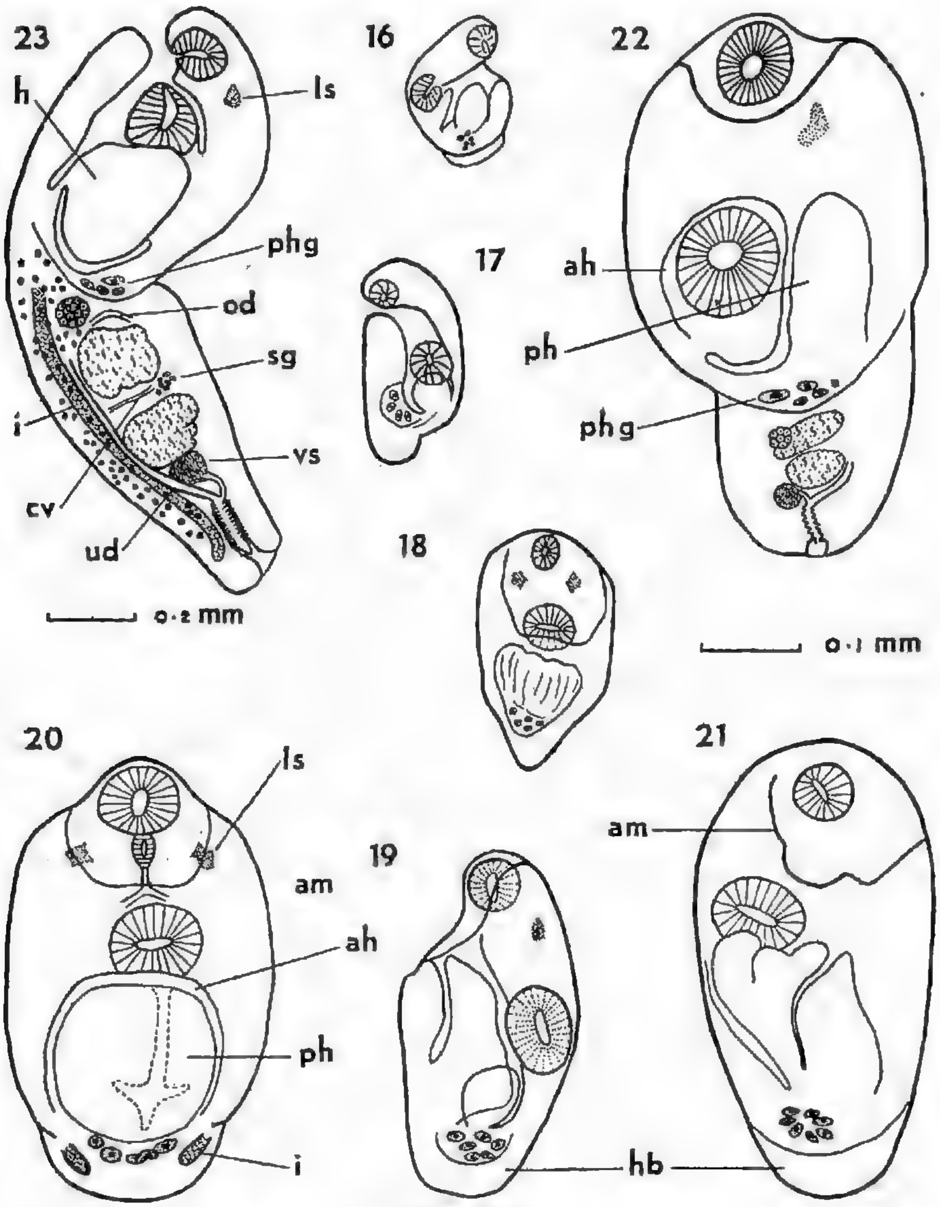

Fig. 16-23
Apatemon intermedius, young stages showing development of holdfasts and cup. 22 shows developing genitalia. 23 shows developing vitellaria.
Fig. 16-22 Drawn to same scale.

It seems to us so surprising that a furcocercaria should make use of two such widely separated types of mollusc as operculate (*Bithynia*) and pulmonate (*Lymnaea* and *Planorbis*) gastropods, that we are of the opinion that Szidat, on the one hand, and Stunkard, Willey and Rabinowitz on the other, were working with different species of the genus. The latter authors gave their reasons in a discussion in which they mentioned differences in the adults as recorded by themselves and by Dubois, as well as differences in the life histories, such as the host snails chosen by the American and European forms, and the differences in time taken for the development of the tetracotyle, although they suggested a possible explanation of the latter.

Larval Stages in Gastropods

In 1947, Johnston and Beckwith gave an account of *Cercaria lessoni*, an *Apatemon* cercaria from *Planorbis isingi*, *Lymnaea lessoni* and *Simlimnea subaquatilis*, and mentioned that *Apatemon intermedius* had been described from the black swan, a common inhabitant of the Murray swamps. It has now been shown experimentally that *Cercaria lessoni* is the larval form of *Apatemon intermedius*.

On 10 May 1947 Miss Beckwith, our former colleague, placed a number of *Lymnaea lessoni* and *Planorbis isingi* in contact with eggs of *Echinoparyphium ellisi* (Johnston and Angel 1949) and of *Apatemon intermedius*. Of eleven laboratory-bred Lymnaeae none became infected with *Apatemon intermedius*, but seven were infected with *Cercaria Echinoparyphii-ellisi*. The twelve Planorbis used were not laboratory raised, but had not been observed giving off cercariae since they had been brought to the laboratory from the Tailem Bend swamps, and were thus classed as "apparently uninfected." On dissection later four were negative, two were found to harbour other infections, while six contained sporocysts which were thought to be probably those of *Cercaria lessoni*, and which in one case contained immature cercariae of this species when dissected 110 days after exposure to the eggs. The present authors repeated this experiment in the summer months two and a half years later. On 29 October 1947 eggs from the duodenal contents of a black swan (which contained adult *Echinoparyphium ellisi* and *Apatemon intermedius*) were put in a small aquarium (A) with laboratory raised *Lymnaea lessoni* and *Planorbis isingi*. A number of the eggs were kept in a small dish and were examined daily. On 1 December 1947 the *Apatemon* eggs began to hatch, and the snails from (A) were removed to an uninfected tank (B); at various times from 21 days afterwards three Lymnaeae died, and proved on dissection to be uninfected; a fourth gave cercariae of *E. ellisi* 79 days after the snails were exposed to the eggs. Of four Planorbis, two were uninfected and two produced *Cercaria lessoni* when first tested 36 days after the miracidia had hatched. On the day when miracidia first appeared, eight Lymnaeae were put in the infected tank A; and on the following day six Lymnaeae were added. Four of the fourteen were disintegrated when found, but the remaining ten which died from 19 to 86 days afterwards, were not infected. However, six Planorbis were added to tank A on the second day, and 35 days afterwards, when they were first isolated, two of them gave off *Cercaria lessoni*; a week later a third produced cercariae. Of the remainder, two were uninfected and one was disintegrated when found 41 days after the exposure.

On the same date as that on which eggs were collected from the duodenal contents of the swan, a number of adult *Apatemon intermedius* were put in water in a small dish, and the eggs which they emitted were placed in a tank with six Lymnaeae and six Planorbis. None of the former became infected, and unfortunately only one of the Planorbis survived, to give a negative result on dissection.

Without this last experiment one might have supposed that the failure of the Lymnaeae to become infected experimentally with *Apatemon* was due perhaps

to an immunity conferred by a previous infection with *Echinoparyphium ellisi*, the eggs of which hatched before those of *Apatemon intermedius*. However, in the previously mentioned experiments, a number of Lymnaeae which escaped infection with *Echinoparyphium ellisi*, also escaped a later infection with *Apatemon intermedius*, and in the last-mentioned experiment, when there was no contamination of the tank with eggs of *Echinoparyphium ellisi*, six Lymnaeae resisted infection with *Apatemon*. It must be concluded, therefore, that *Cercaria lessoni*, as described from *Planorbis isingi*, *Lymnaea lessoni* and *Simlimnea subaquatilis* exists in at least two strains, and that the strain which infects *Planorbis* does not readily infect *Lymnaea*. *Simlimnea subaquatilis* was not used in the experiments, as this snail is not often found, and we have not yet reared it under laboratory conditions.

Cort, McMullen and Brackett (1937), and Cort, Olivier and McMullen (1941) dealt at some length with the problem of multiple infestations of snails by cercariae. In 1937 Cort and his fellow-workers, in a historical survey of multiple infestations, showed that records of double infections of echinostome cercariae with other forms were comparatively uncommon. From their own observations with *Stagnicola emarginata angulata*, they thought it probable that some immunity or antagonism existed between cercariae of *Echinostomum revolutum* and some other species of cercariae (not of echinostomes), since they never appeared in double infections. In 1941 Cort et al., working with cercarial infections of *Physa parkeri*, suggested that some such condition prevented double infections of the cercaria of *Echinoparyphium recurvatum* with the schistosome, *C. physellae* Talbot 1936, and the strigeid, *C. physae* Cort and Brooks 1928, since each of the combinations, according to chance, should have occurred much more often than it actually did.

From December 1937 to September 1950 we have identified only six double infections in 7,087 *Lymnaea lessoni* examined. Three of these involved echinostomes, one of which was coupled with *Cercaria lessoni;* a fourth coupled the latter form with *C. Plagiorchis-jaenschi* Johnston and Angel 1950.

From May 1946 (the last date for which percentage infections of *C. lessoni* were recorded by Johnston and Beckwith) to September 1950, *C. lessoni* has been identified in 57 of 1,991 *Planorbis isingi*, this total comprising 38 of 1,380 from Tailem Bend, none of 417 from Wood's Flat, and 19 of 194 from Bow Hill. No *Lymnaea lessoni* have been found in the Tailem Bend swamps in this period, but four of 133 from Wood's Flat and one of 1,779 from Bow Hill, making a total of five of 1,912, have been found infected with *Cercaria lessoni*. Combining these figures with those given previously shows that *Cercaria lessoni* has been observed in 106 of 5,845 *Planorbis isingi* (1·8%) and in 117 of 5,648 *Lymnaea lessoni* (2%) from December 1937 to September 1950.

Miracidium

Twenty-two days after they were laid (October-November 1947) some eggs showed eye spots; ten days later motile miracidia were present; by the next day all had hatched. The period required for hatching in late spring was thus about 33 days. The miracidia were examined in serum diluted one-half, which had the effect of immobilizing them for examination, but which slowly killed them. The head end (fig. 26) was more distorted by the serum than was the rest of the body, as the actively swimming miracidium appeared quite sharply pointed. The eye spots are kidney-shaped and very dark. On one side, latero-posteriorly to the eye spot, was a pair of flame cells, with a collecting tube which extended nearly to the posterior end, where another flame cell was situated.

Metacercaria

Stunkard, Willey and Rabinowitz (1941) reported of *Cercaria burti* that the larvae grew and developed in the leech and did not encyst until 30 to 42 days, and that none had encysted at 23 days. This is not the case with *Apatemon inter-*

medius, 23-day-old metacercariae of which are enclosed in a thick cyst wall and can only be excysted mechanically with great difficulty. An average of ten such cysts measured 265 by 206 μ, the inner cavity being 205 by 176 μ. Johnston and Beckwith (1947) reported cysts of two sizes from leeches which had been exposed to cercariae 7 and 13 weeks before they were killed. In the smaller cysts (presumably seven weeks old) the cavity measured 205 by 180 μ, while the measurement including the cyst wall, was 295 by 246 μ. From these measurements it would seem that from 23 days to seven weeks of metacercarial development increase in size is in the thickness of the cyst wall. However, the size of the cyst may not necessarily be dependent only on age, as is indicated by a single cyst which was obtained from a leech 23 days after infection, the measurements (338 by 300 μ, with the cavity 270 by 218 μ) being substantially larger than those given for the previous series.

It is perhaps of interest to note that Stunkard et al. were unable to infect with *C. burti* three *Placobdella parasitica* and two *P. rugosa* (belonging to the Rhynchobdellida), whereas *Herpobdella* (Arhynchobdellida) was readily infected; we were not successful in attempts to infect three *Limnobdella australis* (Arhynchobellida) with *C. Apatemon intermedius*, which encysted readily in *Glossiphonia* (Rhynchobdellida). It would seem that *Apatemon* cercariae are not only selective in their choice of leech host, but that the type of leech differs for different species of the genus.

Comparison of fig. 28 with Stunkard's fig. 3 shows that the reserve excretory systems of the two forms as seen at 23 days metacercarial development is substantially the same; we did not observe the terminal vesicles or any calcareous concretions associated with them, but the system was packed with small excretory granules. In our form the median anterior canal as well as the posterior one, joined the transverse canal which lies just posterior to the ventral sucker. Johnston and Beckwith (1947) gave figures showing the commencement of the development of the secondary excretory system in the cercaria.

A series of six 23-day-old metacercariae, stained and mounted, measured from 158 by 113 μ to 225 by 165 μ, the measurements being taken across the greatest width. The metacercariae had attained much the same stage of development as that shown by Stunkard et al. in their fig. 2.

In the original account of *Cercaria lessoni*, the figures of older metacercariae freed from their cysts indicate length about ·33 mm., maximum breadth ·26, fore-body ·25 by ·26, hind-body ·08 by ·13 (at junction with fore-body) for the worm shown in fig. 7 (a ventral view), and ·42 by ·29 for that indicated in fig. 9 (a lateral view).

Juvenile Stages found in the Black Swan

As mentioned earlier, we found numerous juvenile tetracotyliform stages along with adults in the duodenum of a black swan taken at Tailem Bend in October 1947. These young worms were of different sizes and in various stages of development. On three occasions we have found in the stomach of black swans from the same locality *Glossiphonia* leeches, and one of them was heavily infected with the thick-walled cysts of *Apatemon*, distributed in its blood system from the posterior sucker almost to the anterior end. We have found natural infections in two species of *Glossiphonia*, one of them larger, thicker, more leathery and papillose, the other smaller, more slender and semi-transparent, both kinds from Tailem Bend swamps.

The youngest stage found in the swan was a tetracotyle, ·11 by ·10 mm., with the anterior two-thirds more or less spherical and the posterior third broadly rounded; while the cup and holdfast organs were present. Another (fig. 16), with the hind-body merely represented, measured ·15 by ·10 mm., its oral sucker

was ·025 by ·03 mm. and the acetabulum ·03 mm. in diameter, and the cup and holdfast organs were well developed. Another was nearly spherical, ·145 by ·145 mm., with the hind-body scarcely recognisable, but it possessed a well developed cup and small holdfast organs. Measurements of other very juvenile worms were ·16 mm. long by ·10, with a very small post-body, with oral sucker ·03 by ·02 mm., and acetabulum ·05 mm. diameter; ·20 by ·10 mm., with well defined post-body (fig. 17) and with suckers ·025 and ·04 mm. diameter respectively; ·24 by ·13 mm., suckers ·03 and ·05 mm. diameter; ·36 by ·17 mm., suckers ·055 and ·08 mm.; ·43 by ·33 mm.; ·47 by ·25 mm., suckers ·06 and ·08 mm. In longer worms the hind-body becomes relatively more pronounced, but is much narrower than the fore-body—total length ·55 mm., forebody ·40 by ·30, hind-body ·15 by ·2, sex organs recognisable, oral sucker ·08 by ·07, acetabulum

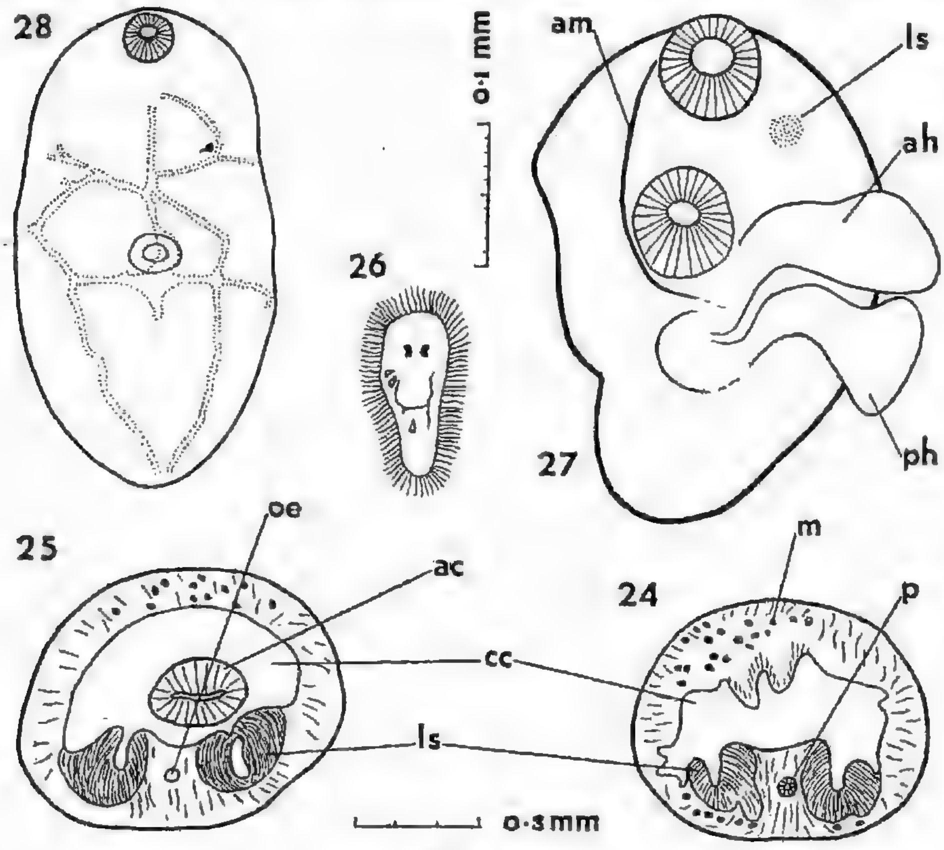

Fig. 24-28

Apatemon intermedius: 24, 25, T.S. anterior part of fore-body, showing lateral suckers; 24 lies in front of acetabulum; 25 shows stalked acetabulum in section. 26, miracidium; 27, metacercaria (tetracotyle) from 23 day-old cyst in *Glossiphonia;* stained preparation showing holdfasts. 28, metacercaria (tetracotyle) from 23 day-old cyst in *Glossiphonia;* drawn from living larva; shows excretory system. Fig. 24-25 to to same scale; 26, 28 sketches; 27, to adjacent scale.

·12 mm. diameter; ·62, fore-body ·47 by ·34, hind-body ·15 by ·25, genital organs recognisable, but closely crowded; ·71, fore-body ·46 by ·38, hind-body ·25 by ·26 mm., with genital organs as in the preceding; 1·0, fore-body, ·55 by ·5, hind-body ·46 by ·27, sex organs as in the preceding two worms. In a specimen, 1·52 mm. long, the fore-body was ·72 by ·52, and the fusiform hind-body ·80 by ·37, oral sucker ·12, acetabulum ·16 mm; vitelline follicles were

present as minute scattered groups, and the gonads were no longer crowded, all the organs of the adult stage being readily recognisable (fig. 23). We have already noted that the smallest ovigerous worm was 2·75 mm. long. The youngest specimen of *A. gracilis* obtained by Szidat (1929, 145) from a duck, twenty hours after he had fed it with infected leeches, was (according to his figure 4) ·36 mm. long and about ·26 mm. in maximum width, and the gonads were already distinguishable.

Because of the presumed loss of S. J. Johnston's type material, we have designated one of our specimens as the substitute type and have deposited it, along with others, in the South Australian Museum, Adelaide.

We desire to acknowledge generous assistance, in our field work from Messrs. G. G. and Bryce Jaensch of Tailem Bend, and Mr. J. Brook of Bow Hill, lower Murray River; and from Mrs. J. Hardy (née A. C. Beckwith), a former colleague. We are also indebted to the Commonwealth Research Grant to the University of Adelaide for the opportunity to carry out the investigation.

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ac, acetabulum; ah, anterior holdfast organ; am, anterior margin of cup in fore-body; av, anterior vas efferens; b, bursa; cc, cavity of cup in fore-body; cv, common vitelline duct; e, egg; fb, fore-body; gc, genital cone; h, holdfast organ; hb, hind-body; hd, hermaphrodite duct; i, intestine; lc, Laurer's canal; ls, lateral s cker; m, muscle; od, oviduct; oe, oesophagus; os, oral sucker; ov, ovary; p, pharynx; ph, posterior holdfast organ; phg, post-holdfast glands; sg, shell glands; tl, t2, anterior and posterior testes; u, uterus; ua, ascending limb of uterus; ud, descending limb of uterus; vd, vas deferens; vf, vitelline follicles; vr, vitelline reservoir; vs, vesicula seminalis; vtd, vitelline duct.

A RECONNAISSANCE SURVEY OF THE SOILS AND VEGETATION OF THE HUNDREDS OF TATIARA, WIRREGA, AND STIRLING OF THE COUNTY BUCKINGHAM

BY R. L. SPECHT

Summary

This paper deals with the woodland communities of the Bordertown and Keith districts in the Upper South-East of South Australia. These fertile communities lie within the vegetation communities of the "Deserts" and show a sharp line of demarcation from them.

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By R. L. SPECHT *

[Read 9 November 1950]

CONTENTS

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SUMMARY

This paper deals with the woodland communities of the Bordertown and Keith districts in the Upper South-East of South Australia. These fertile communities lie within the vegetation communities of the "Deserts" and show a sharp line of demarcation from them.

The climate, soils and vegetation have been studied, and attempts made to correlate the dominant trees and associations with the factors of the environment.

The climate is typical of the Mediterranean region and shows a range in rainfall from 18 to over 20 inches per annum.

Grey soils of heavy texture, a complex of red and grey soils of heavy texture, red-brown earths, solonized woodland soils, meadow podsols, rendzinas, red mallee soils and soils with affinities with the Laffer sand have been observed and mapped.

The distribution of the *Casuarina luehmanni, Eucalyptus calcicultrix, E. leucoxylon, E. camaldulensis, E. largiflorens* and *Melaleuca pubescens* savannah woodland associations within the area has been mapped and investigated in relation to these factors of the environment.

A brief resume of the vegetation of the adjacent "Deserts" is added for contrast.

INTRODUCTION

This reconnaissance survey of the soils and vegetation of portion of the Upper South-East of South Australia is intended as a basis for a pasture survey being carried out by the Waite Agricultural Research Institute, and financed by the Australian Wool Board.

This survey is primarily concerned with the woodland communities of the Keith (Hundred of Stirling) and Bordertown (Hundreds of Wirrega and Tatiara) districts in the Upper South East of South Australia. These fertile communities lie within the mallee-broombush, heath and mallee-heath communities of the "Deserts" and show a sharp line of demarcation from them. The possible relationships between the woodland communities and those of the "Deserts" have been investigated.

The survey has been made by examining the distribution of the soils and vegetation along all the passable surveyed roads of the area. Extrapolation of the boundaries was found unnecessary in most cases, for the roads were relatively close together. However, as most of the surveyed roads of the "Deserts" were impassable, the vegetation there has been correlated and mapped from aerial photographs.

LOCALITY

The Bordertown district, defined by the Hundreds of Tatiara and Wirrega of County Buckingham, South Australia, is the westerly extension of the rich Victorian Wimmera district, and therefore, especially on its eastern extremity, shows marked similarities to the latter. It lies between the so-called Big and Little "Deserts" of the north and south respectively and the Ninety-Mile "Desert" in the west. These "Deserts" are complicated formations of sand dunes formed during the Arid Period of Recent Times (8) and are clothed in a scrubby vegetation of stringybark, pink gum, mallee-heath, heath and mallee-broombush.

The Hundred of Tatiara is drained by two main streams, the Tatiara Creek in the north, and the Nalang Creek in the south. From a south-easterly direction, shallow watercourses enter both these streams which flow in a general westerly direction. The country between the "Deserts" has thus

developed a gently undulating topography. As the fall in the level of the land towards the west is so gradual, the streams become less definite and finally end in a series of shallow swamps on the eastern side of the Hundred of Wirrega.

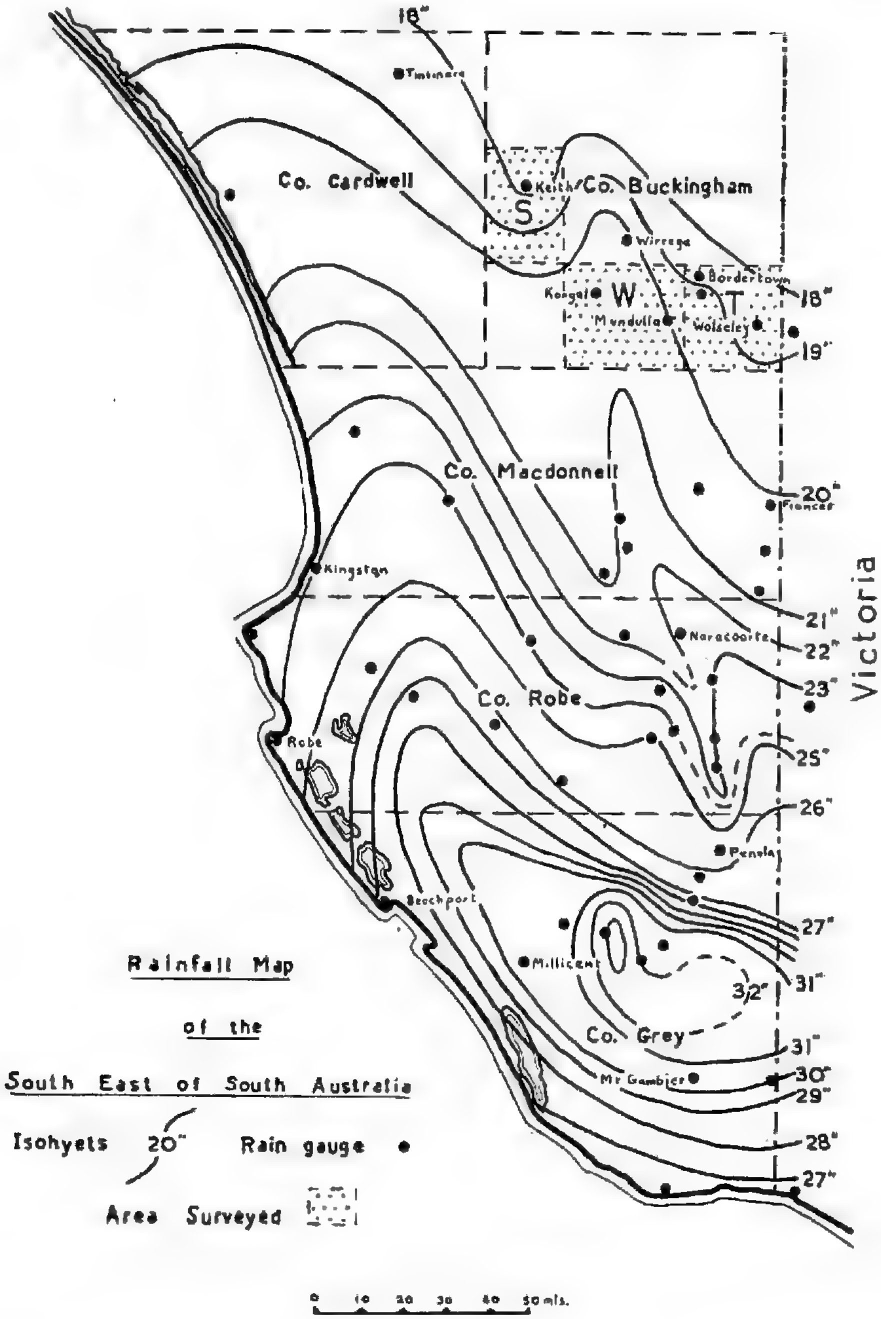

Fig. 1

The drainage of the Hundred of Wirrega is poor, most of the excess water finding its way into numerous swampy hollows. Towards the west, however, the water percolates rapidly through the underlying rocks.

Several ridges of consolidated dune limestone overlain with travertine limestone occur in the Hundred of Wirrega. Three of these, the Cannonball Ridge and the Changwa Ridges, run in a N.N.W. direction, while the others, the Kongal Ridges, which occur further to the west, run almost at right angles to the latter.

The woodland area, which occurs around Keith in the Hundred of Stirling, can be regarded as an extensive expression of a blue gum-pink gum flat. These flats occur scattered throughout the "Deserts" wherever low-lying, wetter pockets of soil have been developed. An area of shallow calcimorphic soils allied to those found to the west of the Hundred of Wirrega occurs at the lower-lying centre of this woodland area.

Figure 1 shows the position of the surveyed hundreds in relation to the South East as a whole.

CLIMATE

The climate is typical of the Mediterranean Region with marked winter rains and summer droughts. This is indicated in Table I which shows the mean monthly rainfall, temperature and relative humidity of Serviceton over a period of 34 years, its average annual rainfall being 19·01 inches. The rainfall map (Figure 1) for the South East of South Australia indicates a gradual increase in rainfall from the north-eastern to the south-western corner of the Bordertown district. This small variation in rainfall, acting with the variable soils of the district, is critical for the distribution of the *Eucalyptus* species prevalent over the area.

The Hundred of Stirling lies in a slightly drier area with Keith township recording an average rainfall of 17·87 inches over a period of 36 years.

Although no temperature or humidity records are available within these districts they have been recorded at Serviceton, a Victorian town just over the border, for several years.

TABLE I

	Yrs.	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Mean Annual
Mean rel. humidity -	15	64	65	69	78	83	88	89	84	79	75	71	70	76%
Mean monthly temp.	24	69.4	68.6	65.6	64.4	54.3	49.1	48.3	49.8	53.4	57.9	63.0	66.8	58.8° F.
Mean monthly rain -	34	52	71	77	128	225	245	236	236	226	176	117	112	19.01 ins.

From these records influential rainfall (P/E greater than 1/3), is found to occur on the average for 7½ months of the year, i.e., from just before April until the beginning of November. Trumble (19) has extrapolated these and other records and has shown that Bordertown and Keith have mean influential rainfall seasons of 7·5 months and 6·9 months respectively.

Trumble has also shown that drought years with less than five months continuous rainfall occur with a frequency of 14% and 22% for Bordertown and Keith respectively.

GEOLOGY

Although very few rocks are exposed, the area seems to be underlain with Miocene limestone. Occasional outcrops of granite occur through the "Desert." A similar outcrop occurs in Section 297 of the Hundred of Wirrega where it has apparently served as a basis for a small, consolidated dune range. Several ridges of consolidated calcareous sandstone, representing former dunes, occur in the Hundred of Wirrega. As mentioned above, these ridges are in two sets at right angles to each other. Travertine limestone appears to overlie the Miocene limestone where it approaches the surface on the rises.

These ridges apparently represent portion of the original coastline before the fluctuations in the sea level in the Pleistocene Period. The irregular directions of these dunes, when considered in relation to the dunes occurring to the north and south, may indicate the position of a complex of dunes around the mouth of a river (private communication from P. S. Hossfeld).

PEDOLOGY

The soils of the Bordertown district are dependent to a large extent upon the topography with its associated drainage relationships. They are all developed from similar parent material, viz. limestone. However, on account of their variability with every change in topography, great difficulty was obtained in obtaining a picture of the soil groups. The soils of the woodland communities can be summarised as follows:—

	Limestone at depth		limestone near surface
	Solonized woodland soil		
	⇅		
Good drainage	red-brown earths	⇄	red mallee soils
	⇅	⇅	⇅
Medium drainage	Complex of grey and red soils of heavy texture (crabholey)	⇄	intermediate soils
	⇅		⇅
Poor drainage	grey soils of heavy texture (crabholey)	⇄	rendzinas
		⇅	
		meadow podsol	

The soils of the "Deserts" owe their origin to the encroachment of sand from the series of dunes left behind as the sea retreated during the Pleistocene Period. With the onset of the Arid Period (Crocker 8) during Recent Times the vegetation was largely destroyed, thus allowing sand drift to occur under the impetus of the prevailing winds. A series of seif dunes with intervening sand flats encroached over the former soils. It would appear that numerous vegetated swamps receiving the drainage from the east existed in the Hundred of Wirrega during the Arid Period and this served as a barrier to sand drift between the Big and Little "Deserts." The complex of shallow rendzina and red mallee soils of the area offers support to this theory. The relationships of these low-lying shallow soils to the surrounding country indicates a similar set-up to that which occurs in County Cardwell at the present day. Here low-lying swampy soils receive the drainage of the Lower South East. A similar swampy area, indicated by identical soils, probably occurred at Keith.

With the release of the pressure of the Arid Period, vegetation recolonised the "Deserts." Through the solonizing effects of cyclic salt, the remaining finer fractions of the sands and the original soils were leached to form the soils as we know them today.

The soils of the "Deserts" support distinctive vegetation. The Little "Desert" to the south of the Bordertown district is composed of deep podsolised sands supporting a stunted *Eucalyptus baxteri* dry sclerophyll vegetation. Small areas of this soil occur throughout the woodland soils of the Bordertown district, and north into the Big "Desert." The Ninety-Mile and Big "Deserts" exhibit a complex of soils supporting heath, mallee-heath and mallee-broombush vegetation. Of these, only the mallee-broombush soil (see profile fig. 7) occurs in the Hundreds of Tatiara and Wirrega. This extends to the south of the Bordertown district between Swede's Flat and the woodland soils of the Hundred of Wirrega. These soils are discussed by Coaldrake in an ecological survey of the Buckingham suite of the Ninety-Mile Plain (6).

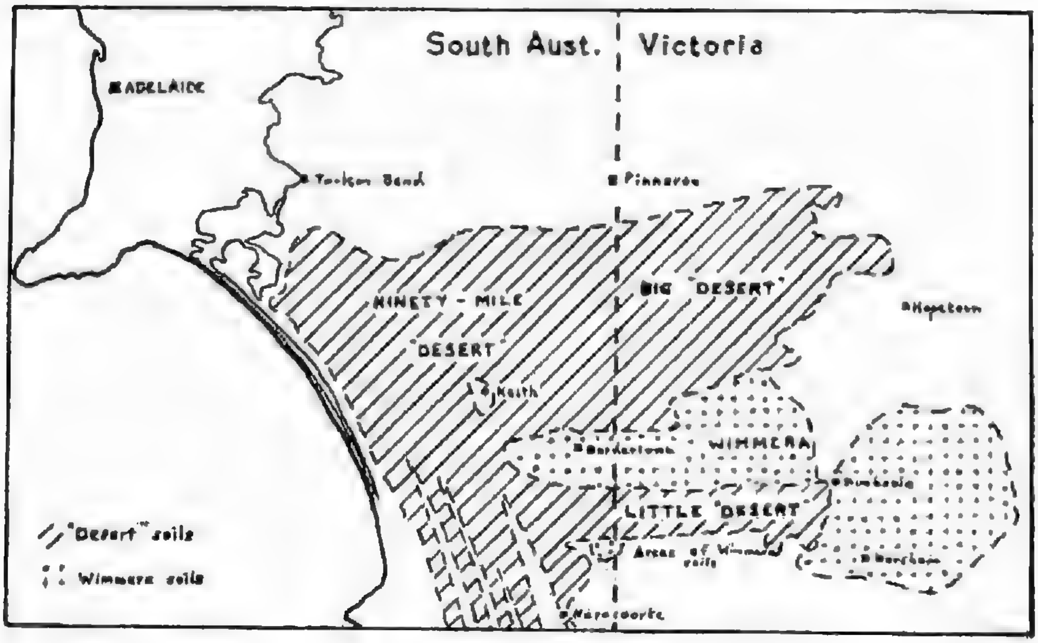

Fig. 2

To the west of Keith the soils agree with those described by Taylor in a "Soil Survey of the Hundreds of Laffer and Willalooka" (17). In the Hundred of Stirling the normal and shallow phases of the Willalooka sand occur near the Hundred of Willalooka. Towards the Hundred of Laffer, the Laffer sands supporting heath and woodland vegetation predominate. The surface sand of the woodland phase (*Eucalyptus fasciculosa – Xanthorrhoea semiplana*) becomes progressively heavier until it grades into the complex of shallow rendzina and red mallee soils near Keith township. These latter soils support a blue gum (*Eucalyptus leucoxylon*) savannah woodland which gradually grades into the *Eucalyptus fasciculosa – Xanthorrhoea semiplana* association. The transition vegetation is allied to that which occurs at Tintinara and in the numerous "blue-gum flats" which occur in the Bangham Scrub of the Little "Desert." All these soils have been solonized to varying degrees under the influence of cyclic salt.

Figure 2 shows the relationship of the soils of the woodland communities to those of the "Deserts."

An account of the soils associated with the woodland communities of the area is given below.

A. Grey soils of heavy texture

In the Hundred of Tatiara, a grey soil of heavy texture is developed from the limestone wherever the area is poorly drained. Such sites are found on the relatively level surface between the watercourses and in the watercourses themselves (see Fig. 3 (1)). These soils are related to the Russian group Sierozerms (14 and 15).

Uniform calcareous clay of pH over 8 continues from 4 to over 6 feet. The soils are "self-mulching," on drying breaking spontaneously into fragments.

On account of their property of great expansion on wetting and contraction and cracking on drying the soils exhibit marked crabholey (gilgai or melon hole) structures some of which are more than 12 feet in diameter. Leeper (12) suggests that "when the soil dries and cracks in summer, pieces of the surface fall down the cracks, adding to the bulk of material below. When this becomes wet again, it swells, and so exerts additional pressure upwards and sideways. The pressure is relieved at the point of weakness to form a puff. The pattern of the points or lines of weakness determines the final pattern of the puff-crabhole system."

The features of the soil are characteristic of the poor drainage conditions. But, although these soils are very wet during the winter, they rapidly dry out and crack as soon as the warm weather appears. The growing season finishes rather abruptly on the puffs and usually slightly before the other soils of the district. The crabholes, however, remain moist for a considerably longer period. These microclimates are conducive to a modification of the ground flora between puff and crabhole. The characteristic dominant of the vegetation of this soil is *Casuarina luehmanni* (the bull oak) with *Eucalyptus largiflorens* (box) confined to watercourses which show the same soil formation.

Profiles from two typical localities are given below:—

Section 270, Hundred of Tatiara

Puff		Crabhole	
0–5″	Dark grey nutty clay	0–6″	Light-grey fine clay
5–″	Yellow-brown clay plus lime	6–26″	Light-grey fine clay plus lime
48″	Continuing	26–38″	Yellow-brown and light-grey mottled clay plus lime
		38″–	Yellow-brown clay plus lime
		48″	Continuing

Section 260, Hundred of Tatiara

Puff		Crabhole	
0–10″	Light-brown clay with some lime	0–14″	Grey clay with slight lime
10–24″	Yellow-grey brown clay with lime	14–36″	Grey-yellow-brown clay with lime
24″	Yellow-brown clay with lime	36″–	Yellow-brown clay with lime increasing with depth
45″	Continuing	45″	Continuing

It will be noted that subsequent to the swelling of the calcareous clay on wetting and the formation of the puffs, there has been erosion of the surface layer of the puffs into crabholes which possess a surface horizon much finer in texture than the puffs.

Analyses show that the surface soil of the puffs has a pH of over 8·0 while that of the crabholes is around 7·0. With depth the pH may increase to over 9·0. Sodium chloride which is in low concentration in the surface soil (0·018–0·045%) increases rapidly with depth (see Table 2). The concentration is by no means critical. Total soluble salts show a corresponding increase with depth. P_2O_5 is relatively high—0·022% in the surface soil.

The puff-crabhole tends to be "ironed out" by repeated cultivation thus creating a more uniform environment for crop or pasture.

These grey soils extend into the Victorian Wimmera and occur around Frances in the Lower South East (see Figure 2).

Millikan (13) has demonstrated an improvement in the yield of wheat on the application of 7 lb. zinc sulphate per acre with the superphosphate on similar soil in Victoria.

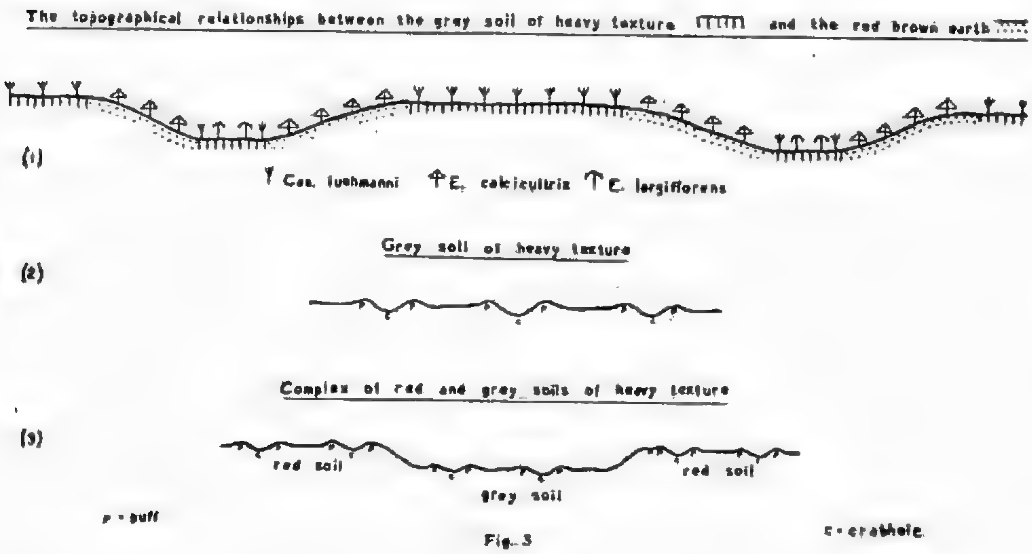

Fig. 3

B. Red-brown earths

At the other extreme of drainage conditions such as occur on the slopes and rises in the vicinity of watercourses (see Fig. 3 (1)), the parent limestone has developed a red-brown earth with a profile typical of that given below:—

Between Section 5 and 6, Hundred of Tatiara

0–6″	Grey-red-brown sandy loam with ironstone buckshot
6–24″	Red-brown nutty clay
24″–28″	Yellow-white clay with much limestone
	Continuing

The pH increases from 6·94 to 9·22 with depth. The good drainage conditions have allowed the clay and lime to be leached out of the upper horizons of the profile whereas the poor drainage conditions where the grey soils of heavy texture occur do not allow much leaching.

The presence of ironstone buckshot is characteristic of these soils and probably imparts the pinkish colour to the sandy loam or sandy clay loam of the A horizon. The ironstone is a remnant of the dissection of the massive laterite of a previous lateritic podsol which presumably covered a large portion of the country during the pluvial Plio-Pleistocene. How it came to be mainly confined to these and intermediate soils and rarely found in abundance in the grey soils of heavy texture is puzzling. Considering the small size of the ironstone, dissection of the country to form its drainage system may have caused the pebbles to drift laterally from the surface of the peneplain into these soils.

The presence of an A horizon of sandy loam or sandy clay loam texture allows much of the moisture to percolate down into the clayey B horizon which has a greater water retaining capacity. As much of the water is retained in the B horizon the surface soil serves as an "insulator" to evaporation on the approach of the dry season. Thus the red-brown earths have a slightly longer growing season than the grey soils of heavy texture which dry out rapidly with the onset of summer. This is borne out in the dominant trees of the area, the bull oak being replaced by the peppermint gum (*Eucalyptus calcicultrix*) and the blue gum (*E. leucoxylon*).

C. Complex of grey and red soils of heavy texture

Intermediate between the red-brown earths and the grey soils of heavy texture, which are typical of good and poor drainage respectively, are areas in which drainage is intermediate. Patches of red-brown and grey soils of several square yards area alternate giving a mosaic of colour and of texture. This complex exhibits crabholey formations as in the grey soils of heavy texture and this, in some cases, may be the cause of the complex. Often the puffs are "ironed out" by repeated cultivation thus obscuring the crabholey formations.

In Section 363, Hundred of Tatiara, the following two profiles were taken about 15 yards apart.

Grey soil

0–6″	Grey-brown clay and slight lime
6–12″	Grey-brown to white clay and much lime
12–22″	Yellow-white clay and much lime
22–36″	Yellow-white clay with pockets of grey clay
36″–	White clay and much lime
40″	Continuing

Red soil

0–8″	Red-brown sandy clay loam and ironstone
8–24″	Red clay
24–30″	Yellow-red-brown clay with lime
30″–	Light-yellow-brown clay with much lime
40″	Continuing

In Section PT 355, Hundred of Tatiara, red soils exhibiting crabholey structures predominate.

Puff

0–27″	Yellow-red-brown clay with lime
27″–	Limestone

Crabhole

0–6″	Grey-red-brown sandy clay with some ironstone
6–12″	Dark yellow-brown clay with lime
12–16″	Yellow-brown clay with lime
16–40″	Light yellow-brown clay with much lime increasing with depth
40″–	Yellow-red-brown clay with some lime
48″	Continuing

It is obvious from the profiles that the soil has been eroded into the crabholes from off the erupted puffs.

Some interesting changes over a short distance are to be observed in the soils near Section 285 of the Hundred of Tatiara. The area alongside the roadway shows marked crabholey structure and carries a relatively dense stand of bull oak. It has apparently been left untouched since the road was surveyed.

In a patch of red soil these profiles can be observed.

Puff		Crabhole	
0–12″	Red-brown nutty clay (slight cracks)	0–10″	Red-yellow-brown silty clay loam
12″–	Yellow-brown clay with lime	10″–	Dark yellow-brown clay
18″	Continuing		Yellow-brown clay with slight lime
		28″	Continuing

while only 18 yards away an area of grey soil shows

Puff		Crabhole	
0–12″	Grey crumby clay + lime (large cracks up to 2″ wide)	0″–	Grey clay
12″–	Yellow-grey clay + much lime	20″	Continuing
18″	Continuing		

On careful examination the red soil groups are found to occupy a slightly elevated and better drained position than the grey soil groups. It appears that the micro-topography has produced conditions for soil formation similar to those occurring on the well-drained slopes and rises and poorly-drained level surfaces and creek-beds (see Fig. 3 (3)). A similar set-up can be seen in the Riverina district (Stephens—private communication) and on the eastern extremities of the Darling Downs.

As would be expected, the growing period, texture and pH are in general intermediate between the heavy grey soils and the red-brown earths. *Eucalyptus calcicultrix* (peppermint gum) tends to dominate this area which is transitional between the bull oak and blue gum communities.

D. Solonized woodland soils

Towards the westerly half of the Hundred of Wirrega and fringing the "Desert" soils, the red-brown earths grade into solonized woodland soils. Superficially, little change in the vegetation is apparent, the blue gum-savannah woodland of the red-brown earths extending imperceptibly on to the solonized woodland soils. As these soils near those of the "Desert," *Xanthorrhoea semiplana* appears, but otherwise there is no indicator species in the vegetation.

Ironstone gravel is usually absent from this soil, the pink tinge of the A horizon of the red-brown earths being replaced by a grey-brown surface soil. The subsoil is yellow-brown to grey in contrast to the red-brown of the red-brown earths, and shows obvious solonization, the top of the clay showing irregular flat domes, with shallow crevices containing the A horizon between them.

The pH of the A and B horizons is about 7·0 whereas the B horizons of the red-brown earths are alkaline (8·5 to 9·2).

A typical profile is shown on Section 240 Hundred of Wirrega.

0–2″	Grey-brown sandy loam + organic matter
2–8″	Pale-brown sandy loam
8–16″	Yellow-brown clay (solonized)
16″–	Limestone

E. Rendzinas

In the Hundred of Wirrega the grey soils of heavy texture which occur in the areas of poor drainage of the Hundred of Tatiara are replaced by a shallow rendzina (the "black stony soil" of the district). This alkaline soil (pH over 8·0) is developed over limestone on extremely flat low-lying areas and grades into red mallee soils, red-brown earths and solonized woodland soils on the higher ground.

Similar soils are present near Keith in the Hundred of Stirling on the lowest-lying area of the district (see Fig. 4).

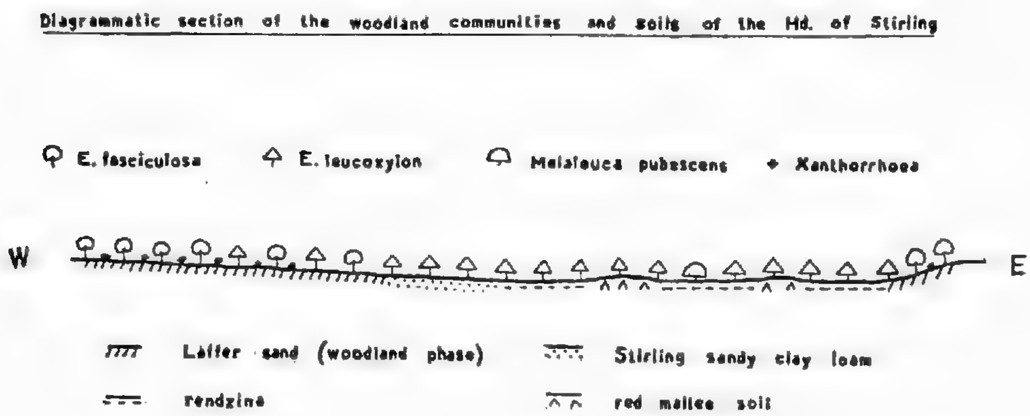

Fig. 4

A typical profile is seen in

Section 523, Hundred of Wirrega

0–3″	Grey clay loam + lime particles
3″	Limestone

As the texture is lighter than that of the heavy grey soils the rendzina rarely cracks in summer. Crabholey formations are never present. Being shallow, these soils dry out rapidly on the onset of warm weather, some two to three weeks before the surrounding soils.

Melaleuca pubescens (dry land tea tree) with occasional *Eucalyptus leucoxylon* (blue gum) is prevalent over this soil.

F. Red mallee soils

The rendzinas grade into red mallee soils and intermediate soils on every slight rise.

On Section 23 Hundred of Wirrega, this profile is present:—

0–8″	Grey-red clay loam + lime
8″	Limestone

On Section 186, Hundred of Stirling, this profile is found:—

0–4″	Red-brown silty clay loam
4″	Limestone

Both these soils show an alkaline pH of over 8·0. They have close affinities to terra rossa soils, but seem to be allied to the red mallee soils which are seen near Coonalpyn (Crocker 8).

Most of the ridges in the Hundred of Wirrega (described in the section on topography) show similar soils wherever the deep sands have been stripped from them. Cannonball Ridge shows red mallee soils while Changwa Ridge shows mainly deep podsolized sands. Sand from these ridges has altered the texture of the rendzinas which occur in the vicinity and has tended to accumulate on the eastern sides.

G. Meadow podsols

In some of the swamps and watercourses where *Eucalyptus camaldulensis* (red gum) occurs the soil approaches that typical of a meadow podsol.

Section 127, Hundred of Wirrega

0–13″	Light-grey sandy clay loam
13–40″	Grey clay with yellow mottling
40″–	Light yellow-grey clay and much lime
44″	Continuing

The mottled B horizon is not invariably present. The soils are very wet for a large portion of the year.

Similar soil occurs at Swede's Flat.

H. Stirling sandy clay loam

The rendzina-red mallee soil complex of the Keith district grades into this slightly solonized soil (see Fig. 4).

A typical profile is seen on the east side of Section 138, Hundred of Stirling.

0–4″	Grey-brown sandy clay loam
4–8″	Grey yellow-brown sandy clay
8″	Limestone

The soil type has been called the Stirling sandy clay loam. It grades into the woodland phase of the Laffer sand.

The pH of the horizons is between 7·5 and 8·0.

This soil has a longer growing season than the calcimorphic soils adjaecnt to it. It supports a *Eucalyptus leucoxylon* savannah woodland.

I. Laffer sand (woodland phase)

The Stirling sandy clay loam grades into the woodland phase of the Laffer sand which exhibits the following profile:—

0–2″	Grey sand and organic matter
2–5″	White sand
5–10″	Yellow-grey sandy clay
10″–	Limestone

This soil has been described by Taylor in the "Soil Survey of the Hundreds of Laffer and Willalooka" (17).

The vegetation is dominated by *Eucalyptus fasciculosa* (pink gum) and Xanthorrhoea semiplana (yacca). A wide transition belt with mixed blue gums and pink gums over a grassy understorey of *Danthonia*, *Lepidosperma congestum* and a few *Xanthorrhoea semiplana* occurs between the woodland phase and the Stirling sandy clay loam (see fig. 4). The *Xanthorrhoeas* increase in density as the woodland phase is approached.

TABLE II
Soils of the woodland areas of the Keith and Bordertown districts.

Soil Group		Depth in inches	Colour	Field texture	pH	T.S.S.	NaCl	P_2O_5	N	Vegetation	Locality
Grey soil of heavy texture	puff	0–5	DG	nutty C	8·37	0·063	0·018	0·027	0·215		
		5–48	YB	c + lime	9·25	0·312	0·150	—	—		
	Crabhole	0–6	LG	C	6·49	0·050	0·026	—	—	Casuarina luehmanni	Section 270 Hd. Tatiara
		6–26	LG	c + lime	8·17	0·341	0·172	—	—	savannah	
		26–38	YB & LG mottled	c + lime	9·08	0·469	0·206	—	—	woodland	
		38–48	YB	c + lime	8·96	0·535	0·243	—	—		
Red and grey soil of heavy texture	puff	0–27	YBB	c + lime	8·64	0·412	0·245	0·022	0·067	Casuarinna luehmanni	Section PT 355 Hd. Tatiara
	Crabhole	0–6	GRB	s.c.	7·46	0·093	0·045	0·022	0·102	savannah	
		6–12	DYB	c + lime	8·70	0·511	0·285	—	—	woodland	
		12–16	YB	c + lime	8·86	0·611	0·345	—	—		
		16–40	LYB	c + much lime	9·01	0·634	0·337	—	—		
		40–48	YRB	c + some lime	9·05	0·514	0·257	—	—		
Red-brown earth		0–5	GRB	s.l. + ironstone gravel	6·94	0·020	0·011	0·018	0·060	E. leucoxylon	Between Sections 5 & 6 Hd. Tatiara
		5–24	RB	nutty C	8·51	0·133	0·060	—	—	savannah	
		24–48	YW	c + much lime	9·22	0·475	0·246	—	—	woodland	
Solonized woodland soil		0–2	DG	l. – s.l.	6·1	0·02	—	0·017	0·11	E. leucoxylon	Section 431 Hd. Wirrega
		2–8	G	s.l.	7·1	0·02	—	0·008	0·04	savannah	
		8–13	DG–G	C	7·1	0·03	—	0·015	—	woodland	
Rendzina		0–3	G	c.l. + lime	8·34	0·052	0·018	0·016	0·324	Melaleuca pubescens with occasional E. leucoxylon	Roadway by Section 523 Hd. of Wirrega
Rendzina		0–3	GB	c.l. + lime	8·04	0·150	0·071	0·034	0·300	Eucalyptus leucoxylon – Melaleuca pubescens	Roadway by Section 139 Hd. of Stirling
Red mallee soil		0–8	GR	c.l. + lime	8·49	0·044	0·010	0·030	0·149	E. leucoxylon	Section 23 Hd. of Wirrega
Red mallee soil		0–4	RB	s.c.l.	8·03	0·028	0·006	0·042	0·081	E. leucoxylon	Roadway by Sect. 186, Hd. of Stirling
Laffer sand woodland phase		0–2	DG–B	s.	6·3	0·02	—	0·013	0·07	E. fasciculosa–	
		2–6	G–W	s.	7·2	0·04	—	0·005	0·02	Xanthorrhoea	
		6–9	GY	c. – s.c.l.	7·8	0·04	—	0·020	0·04	semiplana	
Laffer sand		0–3	G–DG	s.	7·3	0·05	—	0·021	0·13	E. fasciculosa	Section 84 Hd. of Stirling
		3–6	GB–LG	s. – s.l.	8·1	0·03	—	0·008	0·03	E. leucoxylon	
		6–10	B–YB	s.c.l.	8·1	0·05	—	0·007	0·04	Danthonia	
Stirling sandy clay loam		0–4	LB	s.l. – s.c.l.	7·82	—	—	—	—	E. leucoxylon	Section 83 W Hd. of Stirling
		4–13	YB	s.c.	7·95	—	—	—	—		

THE VEGETATION

In discussing the vegetation of the district, an endeavour has been made to correlate the distribution of the dominant trees and formations with the governing factors of their environment, and to indicate from these the naturally occurring associations of the district.

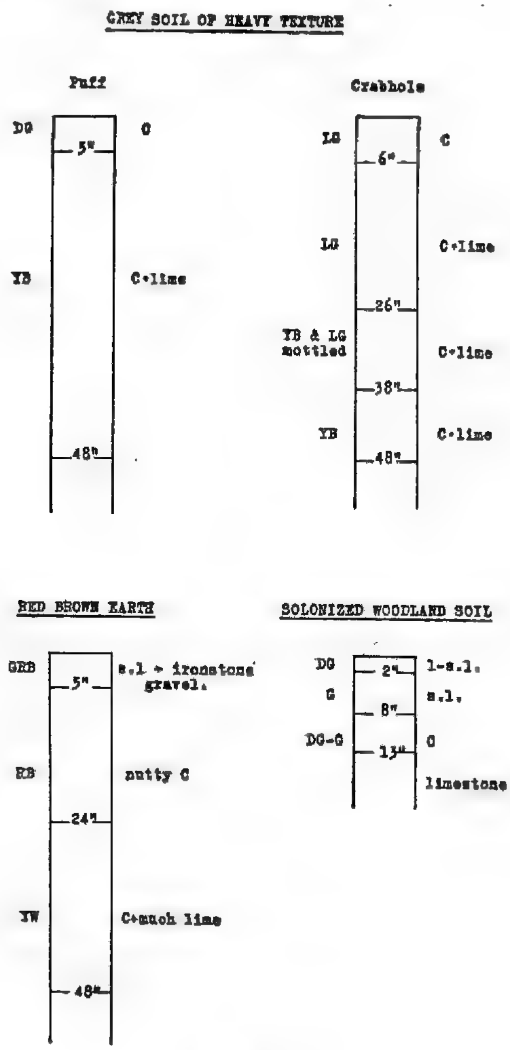

Fig. 5

A. Autecology of the dominant species.

1. *Casuarina luehmanni* (bull-oak).

This species flourishes on the grey soils of heavy texture and extends on to soils marginal to these areas. These marginal soils are usually heavy-textured grey and red soils, although the bull-oak is occasionally found on red-brown earths. However, the presence of lime and, hence, an alkaline pH throughout the soils, is a characteristic of most of the soils where bull-oak predominates. The soils tend to dry out and crack very rapidly on the onset of the dry summer period. This is most marked on the puffs on which the bull-oaks usually occur. It appears from observation that the bull-oak can persist with a slightly shorter growing period than most of the other dominants of the district. It usually occurs in

areas with the rainfall less than 19″ per annum. This limit is actually controlled by the soil itself. For instance, at Frances to the south of the Little "Desert," Tiver (18) has found bull oaks confined to similar soils with an annual rainfall of 20″ and over. A few small stands of bull oak occur on low-lying, heavy grey soils in the Hundred of Wirrega. Here the rainfall is about 20″ per annum.

Although bull oak occurs on the heavy grey soils of the watercourses it usually takes a position on the fringe of the watercourse where the water does not lie as long as in the course itself.

2. *Eucalyptus calcicultrix* (peppermint gum).

The identification of the peppermint gum of the district has been very difficult. A great variation in habit, bark, leaf, bud and fruit characters from area to area and within the same area has caused confusion. Some specimens seem to belong to the species *E. odorata*, some to *E. odorata* var. *angustifolia*, some to *E. calcicultrix*, while many show intermediate characters. Boomsma (4) has shown the complexity of these species and has explained it from an evolutionary standpoint. For the purpose of this paper the peppermint gums will be referred to as *E. calcicultrix*, but they are really a complex with *E. calcicultrix* dominant.

The peppermint gums occur in areas marginal to the bull oaks which have a slightly longer growing season. It is especially noted on the red-brown earths around Custon and to the north of Duke's Highway near the Victorian border. As the rainfall increases towards the west, the peppermint gums on the red-brown earths are replaced by the blue gums (*Eucalyptus leucoxylon*), occasional clumps of *E. calcicultrix* occurring on the top of rises where the drainage causes the red-brown earths to dry out earlier than on the level country.

The peppermint gum is not confined to the red-brown earths but extends onto the complex of grey and red soils of heavy texture. It appears then that the presence of lime (and an alkaline pH of 7-8) in the upper horizons of the soil does not limit its distribution. It is largely influenced by the water relationships within the soil. Such a tolerance has been demonstrated by Specht and Perry (16) for the peppermint gum of the Adelaide Hills.

3. *Eucalyptus leucoxylon* (blue gum).

At about the 19″ isohyet and above, blue gum assumes dominance over the whole of the woodland communities of the Bordertown district, replacing the peppermint gum which exists on areas with a shorter growing season. The blue gum extends into the peppermint gum stands of lower rainfall areas (at least as low as 18″ per annum) as fringing communities on the slopes alongside the red gum (*E. camaldulensis*) or box (*E. largiflorens*) of the watercourses. In its turn peppermint gum occurs on the drier ridges within the areas dominated by blue gums.

Within its distribution range blue gum occurs on red-brown earths, solonized woodland soils, some heavy grey and red soils, and extends onto the rendzina—red mallee soil complex in the Hundred of Wirrega. It tends to be replaced by *Melaleuca pubescens* on the latter soil complex wherever the soil is very shallow. The blue gums extend over small sand ridges of the district but usually there are swamps close at hand.

Throughout the Little "Desert" blue gums occur on flats which often become waterlogged and swampy during winter. Even in summer the subsoil of the flats tends to hold the moisture and hence makes an ideal habitat for the development of blue gums.

It, therefore, appears that *E. leucoxylon* is distributed over many different soils provided the water relations of these soils are suitable for its growth. This

fact has been pointed out by Specht and Perry (16) in discussing the distribution of *E. leucoxylon* in the Adelaide Hills. There the minimum rainfall was found to be 25 inches, but much of this rainfall is lost in run-off in the dissected country. The lower limit of 19 inches per annum found in the Bordertown district is therefore comparable.

The large stand of blue gums at Keith in the Hundred of Stirling is rather puzzling. It is equivalent to a large blue gum flat of the "Deserts" except for the rendzina-red mallee soil complex which occupies the low-lying portion of the district. The rainfall at Keith township averages 17·87 inches per annum over a period of 36 years, while Messrs. Moseley, a couple of miles south-west of Keith, have recorded 18·30 inches over a period of 13 years. It appears then

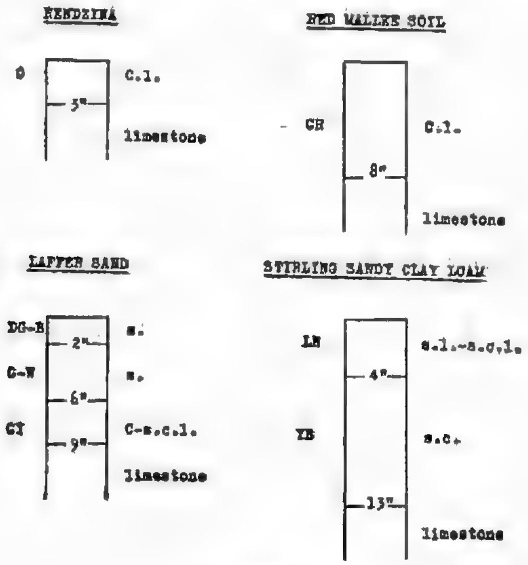

Fig. 6

that the area has an average rainfall somewhere in the vicinity of 18 inches per annum. Considering the nature of the soils—shallow rendzina, red mallee soil, the Stirling sandy clay loam and the woodland phase of the Laffer sand—one would expect *E. calcicultrix* rather than *E. leucoxylon* to be dominant. Blue gums have been recorded in areas with rainfall as low as 15 inches per annum (3 and 11) but always on soils of high water-retaining capacity.

In discussing the formation of the "Deserts" it was suggested that this area of rendzina and red mallee soils represented a swamp during the Arid Period. It is suggested that blue gum was probably one of the dominant trees of this swamp and as the pressure of the Arid Period was released this species spread to occupy its present area. As climate-soil relations today are limiting for these trees, most have developed an atypical twisted appearance resembling that of the pink gum (*E. fasciculosa*) with which it occurs. The leaves, buds and fruits show no noticeable difference from the typical forms of the Tatiara district.

4. *Eucalyptus largiflorens* syn. *E. bicolor* (river box).

E. largiflorens is often confused with the peppermint gums of the area. However, it has the typical box bark and fruits in terminal panicles whereas the peppermint gum tends to have a rough shaggy bark and fruits in axillary umbels.

The tree is confined to the heavy-textured grey soils of the tributaries and watercourses of the Tatiara Creek (see fig. 3 (1)). Most of these watercourses consist of swampy areas along which the water gradually escapes to the west. Consequently they have a long growing period. Although some areas are flooded all the year round, especially after a very wet season, most of the streams dry out during the summer. The soil is alkaline throughout and shows distinct crabholes.

Tiver has noted this box occurring occasionally on the heavy grey soils of the Frances district. It extends through the Wimmera district in similar habitats (Patten—private communication) and is found in equivalent habitats along the River Murray and its tributaries (1 and 20).

5. *Eucalyptus camaldulensis* syn. *E. rostrata* (red gum).

This tree is confined to the watercourses and swamps and replaces *E. largiflorens* where the texture of the surface soils is lighter. The soils usually have meadow podsol affinities but the red gums extend on to the swampy rendzina soils near the end of the Tatiara and Nalang Creeks.

A large area of red gum occurs on Swede's Flat in the south-west corner of the Hundred of Wirrega. This area becomes very wet in winter and is characterised by a series of *Lepidosperma* swamps along its centre.

6. *Melaleuca pubescens* (dry land tea tree).

This tree occurs mixed with blue gums on the shallow soils of the rendzina —red mallee soil complex of the Hundreds of Wirrega and Stirling The rendzinas are rarely wet and boggy in winter. Even after a heavy rain, there are few pools lying about. Most of the excess water soaks rapidly through the limestone which is not far from the surface. Where the soil is very stony the tea tree becomes dominant.

It appears then that the tea tree becomes dominant on alkaline soils which have a very short growing period. This agrees with its distribution elsewhere in South Australia (7).

7. *Eucalyptus fasciculosa* (pink gum).

This gum is prevalent over the woodland phase of the Laffer sand. The soil is low in nutrients and has a low water-retaining capacity. As the texture of the surface soil becomes heavier, blue gums occur as co-dominants and entirely replace the pink gum on the Stirling sandy clay loam.

8. *Savannah woodland formation.*

This formation occurs over the whole of the richer soils of the Tatiara and Keith districts. *Danthonia* spp. with *Stipa* spp. and *Agropyron scabrum* often co-dominant, are prevalent over the whole grassland area. Although there is little variation in the nature of the composition of the native grasses in the understorey, the herbs and introduced legumes vary greatly with the different soils. Towards the "Deserts" *Xanthorrhoea semiplana* becomes prevalent in the understorey and finally gives way to the mallee and sclerophyll communities on the poorer soils of the "Deserts" (see pl. iv, fig. 1).

B. Classification of the plant communities.

A glance at the soil and vegetation of the district and the foregoing discussion on the autecology of the dominant species of the flora will serve to indicate that several distinct vegetational associations and ecotones are present in the area. An association is regarded as any naturally occurring assemblage of plants present over a wide area with similar environment. An ecotone is regarded

TABLE III

Plant associations of the woodland communities of the Keith and Bordertown Districts

Formation	Community	Common Name	Rainfall Range	Soils
Savannah woodland	Casuarina luehmanni association	bull oak	–18″ to 20″ p.a.	Grey soils of heavy texture.
	E. calcicultrix association	peppermint gum	18″ to 19·5″ p.a.	Red-brown earths, red and grey soils of heavy texture.
	E. leucoxylon association	blue gum	18″ to 22+″ p.a.	Red-brown earths, solonized woodland soils, rendzinas, red mallee soil, Stirling sandy clay loam.
	E. camaldulensis association	red gum	19″ to 22+″ p.a.	Meadow podsols and allied soils, some rendzinas.
	E. largiflorens association	box	–18″ to 19″ p.a.	Grey soils of heavy texture in water-courses.
	Melaleuca pubescens association	dry land tea tree	–18″ to 22″ p.a.	Well drained rendzina and red mallee soils.
Sclerophyll woodland	E. fasciculosa-Xanthorrhoea semiplana association	pink gum—yacca	18″ to 22+″ p.a.	Woodland phase of Laffer sand.
	E. leucoxylon-E. fasciculosa ecotone	blue gum—pink gum	18″ to 22+″ p.a.	Transition soils between the two associations. "Blue gum flats."

as a transitional area between two or more associations whose species have overlapping environmental ranges. There is no evidence to assume that any of these ecotones are tension belts, for as far as can be seen the vegetation is relatively stable.

It will be seen that the following associations are present:—

1. *Casuarina luehmanni* association.
2. *Eucalyptus calcicultrix* association.
3. *Eucalyptus leucoxylon* association.
4. *Eucalyptus camaldulensis* association.
5. *Eucalyptus largiflorens* association.
6. *Melaleuca pubescens* association.
7. "Desert" edaphic complex.
   - (a) *E. baxteri* association.
   - (b) *E. fasciculosa–Xanthorrhoea semiplana* association.
   - (c) *E. incrassata–E. leptophylla–Melaleuca uncinata* association.
   - (d) *E. behriana–E. anceps* association.
   - (e) *Xanthorrhoea semiplana–Banksia ornata* association.
   - (f) *E. incrassata*–heath association.
   - (g) *E. diversifolia* association.
   - (h) *E. leucoxylon–E. fasciculosa* ecotone.

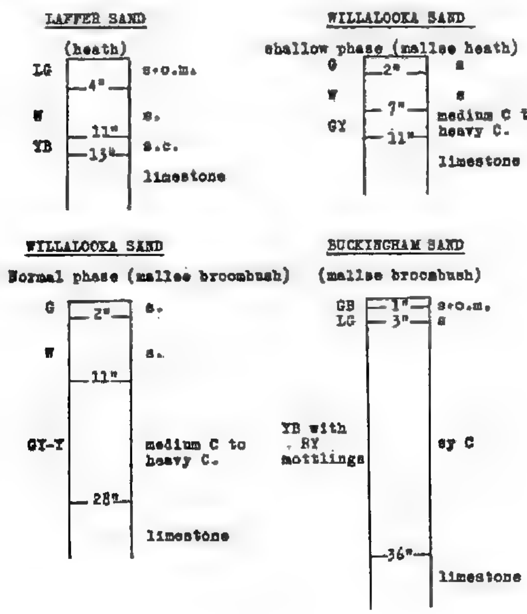

Fig. 7

1. *Casuarina luehmanni* association (see pl. iv, fig. 2).

This savannah woodland association flourishes on the grey soils of heavy texture. The soils are characteristically water-logged in winter and dry out rapidly at the onset of summer. Due to the pronounced crabholey nature of the soil, microclimates are produced on the puffs and the crabholes. The crabholes retain the moisture which runs off the puffs and are consequently very wet in winter and have a longer growing period than the latter which dry out and crack

on the approach of the dry season. These soils occur where the rainfall is less than 19 inches per annum, but a few areas occur, supporting bull oak, in rainfall greater than this.

Although *Danthonia* and *Stipa* are the dominants of the native savannah understorey, agriculture, with top-dressings of superphosphate, and grazing has rapidly altered the former balance of species. Wimmera rye grass (*Lolium rigidum*), silver grass (*Vulpia myuros*) and other introduced herbs have replaced the original dominants. Statistical analysis by the Levy Point Quadrat method (9) has shown the following percentages for the relatively untouched vegetation under the bull oaks on Section 318 of the Hundred of Tatiara.

	Puff	Crabhole
Vegetation hits per 100 points - -	73	40
Bare ground, per 100 points - -	34·0	62·0

Danthonia spp. - - - - - -	27·4%	37·4%	
Danthonia sp. (prominent in crabholes)	4·1	30·0	Percentage † overlapping cover
Stipa eremophila - - - - -	30·1	—	
**Vulpia myuros* - - - - - -	9·6	—	
**Plantago bellardii* - - - - -	5·5	—	
Angianthus strictus - - - - -	9·6	—	
Myriocephalus rhizocephalus - -	—	10·0	
**Cryptostemma calendulaceum* - -	—	7·5	
**Hypochoeris radicata* - - - - -	2·7	—	
Crassula sieberiana - - - - -	2·7	—	
**Medicago minima* - - - - -	4·1	—	
Miscellaneous - - - - - -	4·2	15·1	

(* denotes introduced plants)

† Percentage overlapping cover indicates the percentage of each species hit per 100 points.

It will be noticed that the crabholes and puffs differ greatly in floristics due to their extreme microhabitats.

A list of associated species in this association is given in the appendix. It will be seen that the association is richer in species than most of the other woodland associations. This may be a result of the varied habitats which exist on this soil.

2. *Eucalyptus calcicultrix* association (see pl. iv, fig. 3).

As the length of the growing season increases, the *Casuarina luehmanni* association gives way to the *Eucalyptus calcicultrix* association. This association has a savannah woodland formation. The understorey varies slightly with the soils. On the marginal grey soils of heavy texture and on some grey and red heavy-textured soils the crabholey formations induce the same micro-floras as are evident in the *Casuarina luehmanni* association. On the red-brown earths, however, the topography is relatively level and the understorey more uniform in composition. *Danthonia* is the dominant genus of the ground flora in the natural vegetation. However, many introduced species have altered the composition of the flora.

Statistical analysis by the Levy Point Quadrat method has revealed the following percentages of species occurring in a roadside between Sections 108 and 110 of the Hundred of Wirrega. The soil is transitional between a red-brown earth and some of the heavy grey and red soils.

Vegetation hits per 100 points	61	
Bare ground, per 100 points	49·5	
Danthonia sp.	72·4%	Percentage overlapping cover
**Poa bulbosa*	13·9	
Stipa sp.	1·6	
**Romulea rosea*	5·7	
Erodium botrys	1·6	
**Trifolium subterraneum*	1·6	
Miscellaneous	3·2	

(* denotes introduced species)

A list of species occurring in this association is given in the appendix. It will be noted that the association shows species which occur either in the *Casuarina leuhmanni* association or the *E. leucoxylon* association. The soils of the *E. calcicultrix* association are transitional between these two associations.

3. *Eucalyptus leucoxylon* association (see pl. iv, fig. 4).

This association replaces the *E. calcicultrix* association at about the 19-inch isohyet and wherever the water relations within the soil are favourable. The association is a savannah woodland formation with an understorey similar to that of the previous association where it occurs on red-brown earths and solonized woodland soils. A list of species recorded in this association is included in the appendix. The following percentages of species were obtained from a roadside between Sections 276 and 277 of the Hundred of Wirrega. This soil is a red-brown earth.

Vegetation hits per 100 points	76	
Bare ground, per 100 points	36·0	
Danthonia sp.	49·1%	Percentage overlapping cover
Stipa sp.	15·9	
**Poa bulbosa*	4·6	
**Vulpia myuros*	5·3	
**Trifolium angustifolium*	10·6	
**Romulea rosea*	2·6	
Leptorrhynchus squamatus	2·6	
Oxalis corniculata	2·0	
Miscellaneous	7·3	

(* denotes introduced species)

The *E. leucoxylon* association occurring on rendzinas and red mallee soils at Keith is essentially similar to that of the Bordertown district. Small variations due to the alkaline soils are apparent in the understorey (see appendix).

4. *Eucalyptus camaldulensis* association (see pl. v, fig. 1).

This association follows watercourses and fringes swamps wherever the surface soil is lighter than a clay. Often trees are seen growing throughout a swamp but if the water is persistent for long periods the red gums are confined to the fringe of the average low water mark.

A list of associated species is given in the appendix.

5. *Eucalyptus largiflorens* (see pl. v, fig. 2).

From the evidence available in this district it is difficult to define the *E. largiflorens* as a definite association, for *Casuarina luehmanni* usually occurs associated

with it on the heavy grey soils of the watercourses. However, it is quite often noted that the bull oak tends to form a fringing community along the edge of the watercourses while the box is left alone in the shallow stream-bed where it may be swamped for most of the year. A well-defined association with this species as dominant has been recorded along the Murray and its tributaries by Wood (20) and Beadle (1). The understorey of this association on the Murray watersheds varies considerably depending on its locality, and shows few species identical with those recorded for the Bordertown district. Most of the species of the *Casuarina luehmanni* association are found in this association.

6. *Melaleuca pubescens* association (see pl. v, fig. 3).

This association is well defined in the Lower South-East, especially on the terra rossas of the Woakwine Range (7). It is approached in the Bordertown and Keith districts in only a few localities on ridges of red mallee soils and on very stony, well-drained rendzinas. In most cases the tea tree is associated with blue gum, forming an ecotone between the *Melaleuca pubescens* association and the *E. leucoxylon* association.

A list of associated species is recorded in the appendix. *Danthonia* and *Stipa* are the dominants of the savannah understorey, but have been displaced by the introduction of *Carthamus lanatus* and *C. glaucus* (the star thistle) in many areas. These species all thrive on the well-drained alkaline soils.

7. *"Desert" edaphic complex.*

A complex of associations and ecotones exists on the solonized and podsolised soils of the "Deserts." Coaldrake (6) gives a detailed account of these associations in an ecological survey of the Buckingham suite of the Ninety-Mile Plain. Jessup (11) has dealt with some of the associations which occur on the western extremity of the "Desert," and Crocker (7) with some of the southern extremity. Taylor in his "Soil Survey of the Hundreds of Laffer and Willalooka" (17) has indicated some of the major vegetation communities which exist in these Hundreds. This vegetation extends into the Hundred of Stirling and to a limited degree into the western edge of the Hundred of Wirrega. It is composed of the following associations:—

(1) *Xanthorrhoea semiplana – Banksia ornata* association (heath) occurs on the normal and shallow phases of the Laffer sand. This association has numerous species which often assume co-dominance within the association (see pl. vi, fig. 2).

(2) *Eucalyptus fasciculosa – Xanthorrhoea semiplana* association (pink gum, yacca) occurs on the woodland phase of the Laffer sand. The associated species are essentially sclerophyllous (see appendix). Occasional blue gums occur throughout the pink gums.

(3) *Eucalyptus incrassata – E. leptophylla – Melaleuca uncinata* association (mallee-broombush) is found on the normal phase of the Willalooka sand (see pl. vi, fig. 3).

(4) *Eucalyptus diversifolia* association occurs wherever the limestone is close to the surface in the shallow phase of the Willalooka sand. The associated vegetation is scrubby, with heath plants and some *Melaleuca uncinata* (see pl. vi, fig. 4).

(5) *Eucalyptus incrassata – heath* association occurs on the shallow phase of the Willalooka sand.

The Bangham Scrub of the Little "Desert" shows predominantly deep podsolised sands supporting a *Eucalyptus baxteri* association with *E. leucoxylon* occurring on small, damp hollows. The *E. baxteri* tends to be stunted in comparison with the trees which occur in the higher rainfall of the Lower South-East (see pl. vi, fig. 1). It continues north into the Big "Desert" wherever deep sandy ridges occur. The association is a sclerophyllous woodland with an understorey essentially similar to that described by Crocker (7).

A mallee-broombush (*E. incrassata – E. leptophylla – Melaleuca uncinata*) association is prevalent between Swede's Flat and the woodland communities of the Bordertown district. The soil consists of a shallow sand (4-6 inches deep) over a deep red-mottled clay which shows marked solonization. This soil markedly differs from that of the same association in the Hundreds of Willalouka, Laffer and Stirling—the normal phase of the Willalooka sand. The association occurs on similar soils to the north of the Bordertown district. Coaldrake (6) has termed this soil type the Buckingham sand.

Eucalyptus behriana occurs mixed with *E. anceps* and an occasional mallee form of *E. calcicultrix* on grey soils of heavy texture marginal to the Big "Desert" communities near the Victorian border. A stand of *E. behriana* on its own is to be seen on Section 439 of the Hundred of Tatiara. These mallee communities have been grouped for convenience under a *E. behriana – E. anceps* association.

8. *Eucalyptus leucoxylon – E. fasciculosa ecotone* (see pl. v, fig. 4).

A transitional community of mixed *E. leucoxylon* and *E. fasciculosa* occurs between the *E. leucoxylon* association and the *E. fasciculosa – Xanthorrhoea semiplana* association of the Hundred of Stirling (see fig. 4). The former occurs on rendzinas, red mallee soils and the Stirling sandy clay loam, and the latter on the woodland phase of the Laffer sand. The soils grade the one into the other with a corresponding transition of one plant association into another. The understorey of the ecotone is dominated by *Danthonia* and *Stipa* on the blue gum side, then *Lepidosperma congestum*, and finally *Xanthorrhoe, Lepidosperma congestum* and other heath species on the pink gum – yacca side.

The "blue gum flats" of the Bangham Scrub in the Little "Desert" can be classed in this ecotone. These damp hollows occur within the *E. baxteri* association of the deep podsolised sands and are dominated by *E. leucoxylon*. Occasional trees of *E. fasciculosa* often occur around the fringe of the "flat" and are sometimes co-dominant. The understorey is usually an admixture of grasses (*Danthonia* and *Stipa*) with a few sclerophyllous bushes from the surrounding *E. baxteri* association.

The *E. leucoxylon – E. fasciculosa* association which Crocker records near Bool Lagoon and south of Lucindale in the Lower South-East (7) would be better placed as an ecotonal community between the *E. leucoxylon* and the *E. fasciculosa – Xanthorrhoea* associations. (In the Lower South-East the yacca is usually *X. australis*, while *X. semiplana* tends to predominate in the Upper South-East).

The herb stratum of this ecotone showed the following percentage composition on the roadside near Section 95W of the Hundred of Stirling.

Vegetation hits per 100 points	47
Bare ground, per 100 points	53·0

Stipa sp.	15·4%	Percentage overlapping cover
Neurachne alopecuroides	11·0	
**Vulpia myuros*	8·8	
Danthonia sp.	3·3	
Lepidosperma congestum	3·3	
Lepidosperma carphoides	2·2	
Sedge (unidentified)	5·5	
**Trifolium arvense*	19·7	
**Trifolium procumbens*	5·5	
**Trifolium glomeratum*	2·2	
Caesia vittata	12·1	
**Hypochoeris radicata*	4·4	
Miscellaneous	6·6	

(* denotes an introduced species)

A list of associated species is given in the appendix.

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APPENDIX

Comparative floristic lists are given for seven major vegetational groups occurring within the area.

(1) *Casuarina luehmanni* association.
(2) *Eucalyptus calcicultrix* association.
(3) *E. leucoxylon* association occurring on red-brown earths and solonized woodland soils.
(4) *E. leucoxylon association* and *E. leucoxylon–Melaleuca pubescens* ecotone occurring on rendzinas and red mallee soils.
(5) *E. fasciculosa–Xanthorrhoea semiplana* association
(6) *E. leucoxylon–E. fasciculosa* ecotone.
(7) *E. camaldulensis* association.

No indication is given as to the percentage frequency of each plant, the x only indicating the presence of that species within that group. The nomenclature of the species is that given by Black (2). An asterisk before the name of a species indicates that the species have been introduced into South Australia.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Marsilea drummondii	—	—	—	—	—	—	x
Potamogeton tricarinatus	—	—	—	—	—	—	x
Themeda australis	x	—	x	x	—	x	—
Neurachne alopecuroides	—	—	—	—	x	x	—
Panicum prolutum	x	x	—	—	—	—	x
*Phalaris minor	x	—	—	—	—	—	—
*P. tuberosa	—	—	x	—	—	—	—
Stipa eremophila	x	x	x	x	x	x	—
Deyeuxia quadriseta	—	—	—	—	—	—	x
*Molineria minuta	—	—	x	x	—	x	x
*Avena fatua	x	x	x	x	—	x	—
Danthonia caespitosa	x	x	x	x	x	x	x
*Briza minor	—	x	x	—	—	—	—
Eragrostis brownii	—	x	x	—	—	x	—
*Poa annua	—	—	x	—	—	—	—
*P. bulbosa	x	x	x	—	—	—	—
*Vulpia myuros	x	x	x	x	x	x	—
*Scleropoa rigida	x	—	—	x	—	—	—
*Bromus rigidus	x	x	x	x	x	x	x
*B. rubens	x	—	x	—	—	—	—
*B. mollis	—	x	x	—	—	—	x
*Brachypodium distachyon	x	—	—	—	—	—	—
*Cynodon dactylon	—	—	—	—	x	—	—
Chloris truncata	—	—	—	—	—	—	x
*Lolium rigidum	x	x	x	x	—	x	x
Agropyron scabrum	x	x	x	x	—	—	—
*Hordeum murinum	x	x	x	x	—	x	x
*H. maritimum	x	x	x	x	—	—	x
Scirpus antarcticus	x	—	—	—	—	—	—
Eleocharis acuta	x	x	—	—	—	—	x
Lepidosperma congestum	x	x	x	x	x	x	—
L. viscidum	—	x	x	—	—	—	—
L. carphoides	—	—	—	—	x	x	—
Gahnia lanigera	—	—	—	x	—	—	—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Chorizandra enodis	x	x	—	—	—	—	—
Carex inversa	x	—	—	—	—	—	—
Juncus bufonius	x	x	—	—	—	—	—
J. prismatocarpus	—	—	—	—	—	—	x
J. pauciflorus	x	x	x	—	—	—	x
Dianella revoluta	—	—	—	—	x	x	—
Burchardia umbellata	—	—	—	—	x	—	—
Anguillaria dioica	—	—	—	—	—	x	—
Caesia vittata	—	x	—	—	—	x	—
Chamaescilla corymbosa	—	—	—	—	—	x	—
Bulbine bulbosa	x	x	—	—	—	—	—
Dichopogon fimbriatus	x	—	—	—	x	x	—
Xanthorrhoea semiplana	—	—	—	—	x	x	—
X. australis	—	—	—	—	x	x	—
*Romulea rosea	—	x	x	x	—	—	—
*Homeria collina	—	—	—	x	—	—	—
Casuarina stricta	—	—	—	x	—	x	—
C. luehmanni	x	—	—	—	—	—	—
C. muelleriana	—	—	—	—	x	—	—
Hakea rugosa	—	—	—	—	x	x	—
Banksia ornata	—	—	—	—	x	—	—
Loranthus exocarpi	x	—	—	—	—	—	—
L. linophyllus	x	—	—	—	—	—	—
*Rumex brownii	x	x	x	—	—	—	x
*R. acetosella	—	—	x	x	—	—	—
*Polygonum aviculare	—	—	x	—	—	—	—
Chenopodium pseudomicrophyllum	x	—	—	—	—	—	—
Ptilotus exaltatus	x	—	—	x	—	—	—
P. macrocephalus	—	—	x	—	—	—	—
P. spathulatus	x	—	—	—	—	—	—
Claytonia australasica	—	—	—	—	—	—	x
*Cerastium semidecandrum	—	—	x	x	—	x	x
Spergularia rubra	x	—	x	—	—	—	—
*Vaccaria segetalis	—	—	x	—	—	—	—
Clematis microphylla	—	—	—	—	x	x	—
Ranunculus lappaceus	—	—	—	—	—	x	—
*Papaver sp.	—	—	—	x	—	—	—
*Fumaria parviflora	—	—	—	x	—	—	—
*Sisymbrium orientale	—	—	—	x	—	—	—
Lepidium hyssopifolium	—	—	x	x	—	—	—
Drosera glanduligera	—	—	—	—	—	x	—
D. whittakeri	—	—	x	—	—	x	—
D. auriculata	—	—	x	—	—	—	—
Crassula sieberiana	x	—	—	—	—	—	—
C. pedicellosa	x	—	x	x	x	x	x
Bursaria spinosa	—	—	—	—	x	x	—
Billardiera scandens	—	—	—	—	x	—	—
Acaena ovina	—	—	x	x	—	—	—
Acacia acinacea	—	x	—	—	—	—	—
A. dodonaeifolia	—	—	—	—	—	x	—
A. pycnantha	—	x	—	—	—	—	—
A. rupicola	—	—	—	x	—	—	—
A. farinosa	—	x	—	—	—	—	—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Eutaxia microphylla	x	—	—	—	x	—	—
Phyllota pleurandroides	—	—	—	—	x	—	—
*Trifolium procumbens	x	x	x	—	x	—	—
*T. tomentosum	x	x	—	x	—	—	—
*T. glomeratum	—	—	x	x	x	x	x
*T. subterraneum	—	x	x	x	—	—	—
*T. scabrum	x	—	x	x	—	—	—
*T. striatum	—	x	—	—	—	—	x
*T. arvense	—	—	x	x	x	x	x
*T. angustifolium	x	x	x	x	—	x	—
*Medicago sativa	—	—	x	—	x	x	—
*Medicago tribuloides	x	—	—	x	—	—	—
*M. denticulata	x	x	x	—	—	—	x
*M. minima	—	x	x	x	x	x	x
Swainsona procumbens var. parviflora	x	—	—	—	—	—	—
Kennedya prostrata	—	—	—	x	—	x	—
Geranium pilosum	x	—	—	—	—	—	—
*Erodium cygnorum	—	—	x	—	—	—	—
*E. botrys	x	x	x	x	x	x	x
*E. moschatum	—	—	x	x	—	—	x
*E. cicutarium	—	—	x	—	—	—	x
Pelargonium rodneyanum	—	—	x	—	—	—	—
Oxalis corniculata	x	x	x	x	—	—	x
*O. cernua	—	—	—	—	—	x	—
Euphorbia drummondii	x	—	x	x	—	—	—
Pimelea humilis	x	—	—	—	—	—	—
Lythrum hyssopifolia	x	x	x	x	—	—	x
Leptospermum myrsinoides	—	—	—	—	x	—	—
Melaleuca pubescens	—	—	—	x	—	—	—
M. uncinata	—	—	—	—	x	—	—
Eucalyptus camaldulensis	—	—	—	—	—	—	x
E. leucoxylon	—	—	x	x	—	x	—
E. fasciculosa	—	—	—	—	x	x	—
E. calcicultrix	—	x	—	—	—	—	—
*Oenothera odorata	—	—	—	x	x	x	—
Halorrhagis heterophylla	x	—	x	x	—	—	—
Hydrocotyle laxiflora	—	—	—	—	x	—	—
Bupleurum semicompositum	—	—	—	x	—	—	—
Eryngium rostratum	—	—	—	—	—	—	x
Astroloma humifusum	—	—	—	—	x	—	—
*Anagallis arvensis	x	x	—	x	x	x	—
*A. femina	x	x	—	x	x	x	—
*Erythraea centaurium	x	x	x	x	—	x	—
Convolvulus erubescens	x	x	x	x	—	—	x
*Heliotropium europaeum	—	—	—	x	—	—	—
*Lithospermum apulum	—	—	—	x	—	—	—
*Echium plantagineum	—	—	x	—	—	—	—
Teucrium racemosum	x	—	x	—	—	—	—
Mentha saturejoides	x	x	—	—	—	—	—
*Marrubium vulgare	—	—	—	x	—	—	—
Solanum nigrum	x	—	—	x	—	x	—
*Linaria elatine	—	—	x	x	—	—	—
*Bartschia latifolia	x	x	—	—	—	—	—

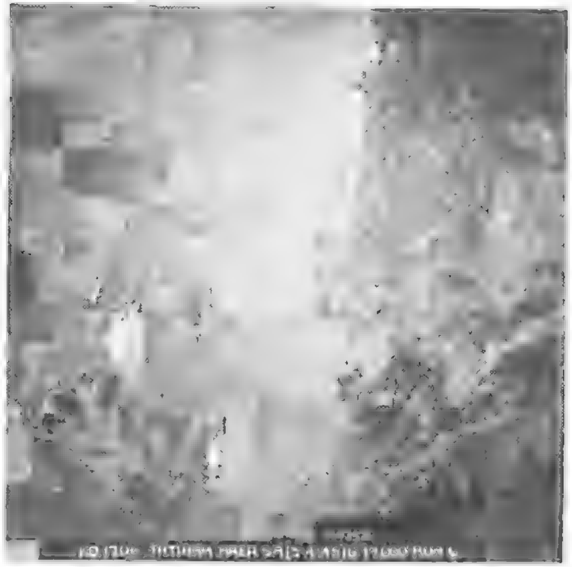


Fig. 1. Aerial photograph showing the sharp line of demarcation between the savannah woodland communities of the Bordertown district and the "Desert" communities (dark area).

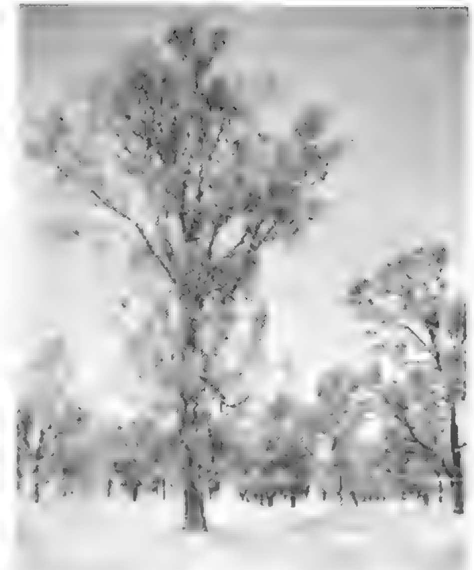


Fig. 2. *Casuarina Luehmanni* association on grey soils of heavy texture (crabholey) near Wolseley.

Fig. 3. *Eucalyptus calcicultrix* association on red-brown earths near Bordertown.

Fig. 4. *Eucalyptus leucoxylon* association on red-brown earths at Bordertown.

Fig. 1. *Eucalyptus camaldulensis* association along the Nalang Creek near Bordertown.

Fig. 2. *Eucalyptus largiflorens* association on the grey soils of heavy texture of a tributary of the Tatiara Creek.

Fig. 3. *Melaleuca pubescens* association on shallow well-drained rendzinas two miles west of Mundalla.

Fig. 4. *Eucalyptus leucoxylon* – *E. fasciculosa* ecotone at Keith.

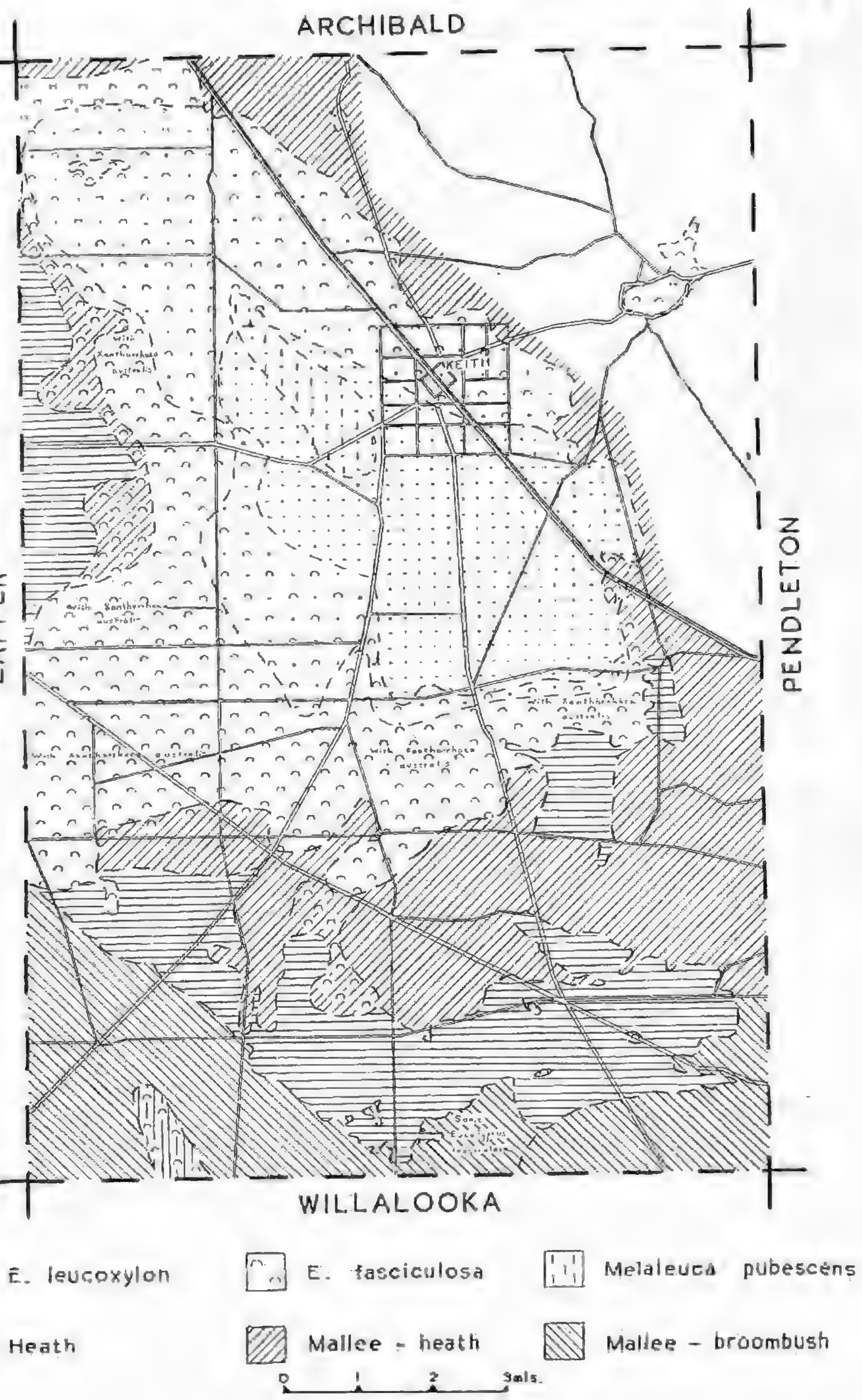
Fig. 1. *Eucalyptus baxteri* association on the deep podsolized sands of the Baugham Scrub. *Banksia marginata* and *Leptospermum myrsinoides* are prevalent in the sclerophyllous understorey.

Fig. 2. Heath (*Xanthorrhoea semiplana* – *Banksia ornata* association) on the normal phase of the Laffer sand, west of Keith.

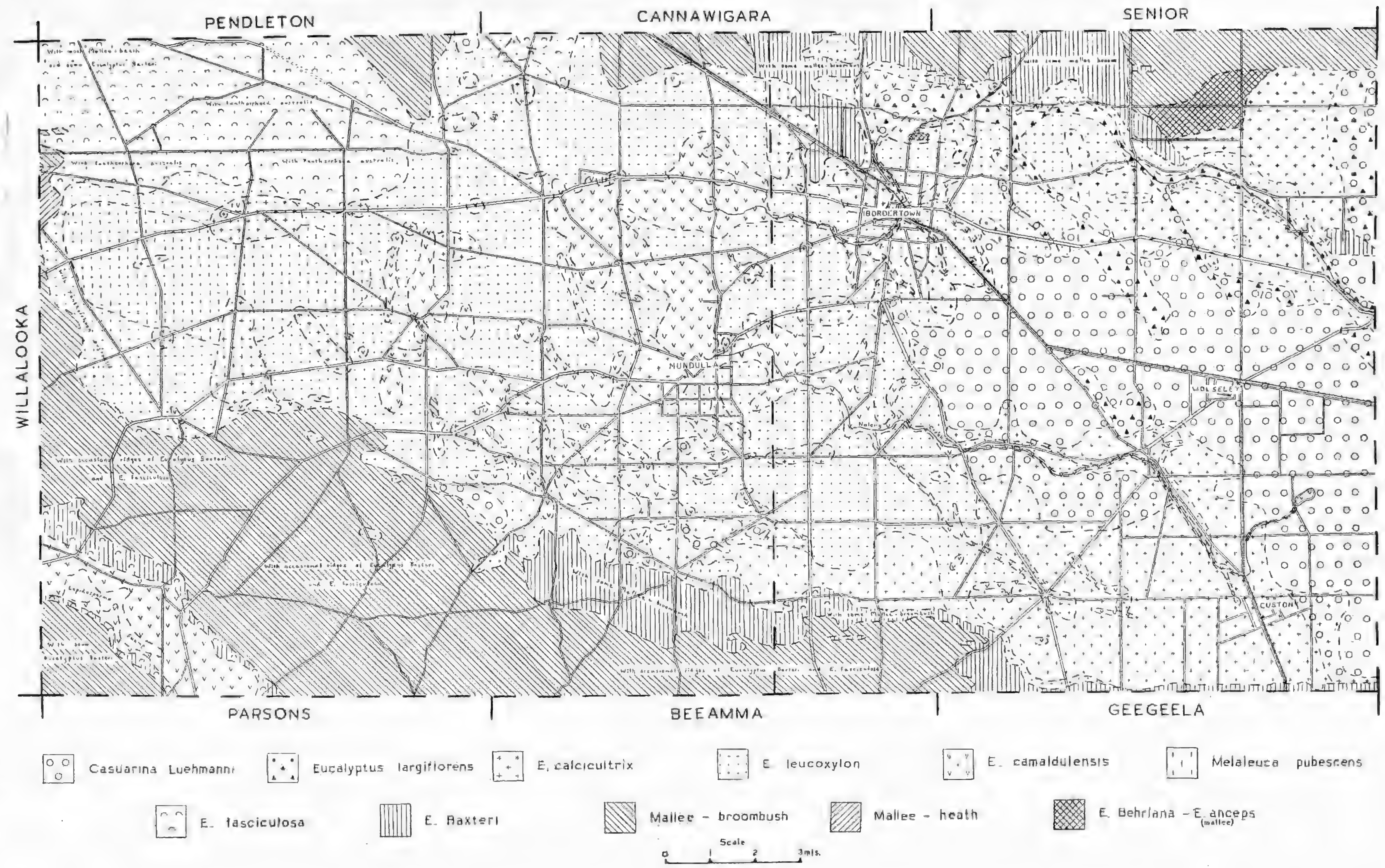
Fig. 3. *Eucalyptus incrassata* – *E. leptophylla* – *Melaleuca uncinata* (mallee - broombush) association on the Buckingham sand 10 miles north of Wolseley.

Fig. 4. *Eucalyptus diversifolia* with some *E. incrassata* on shallow limestone soil.

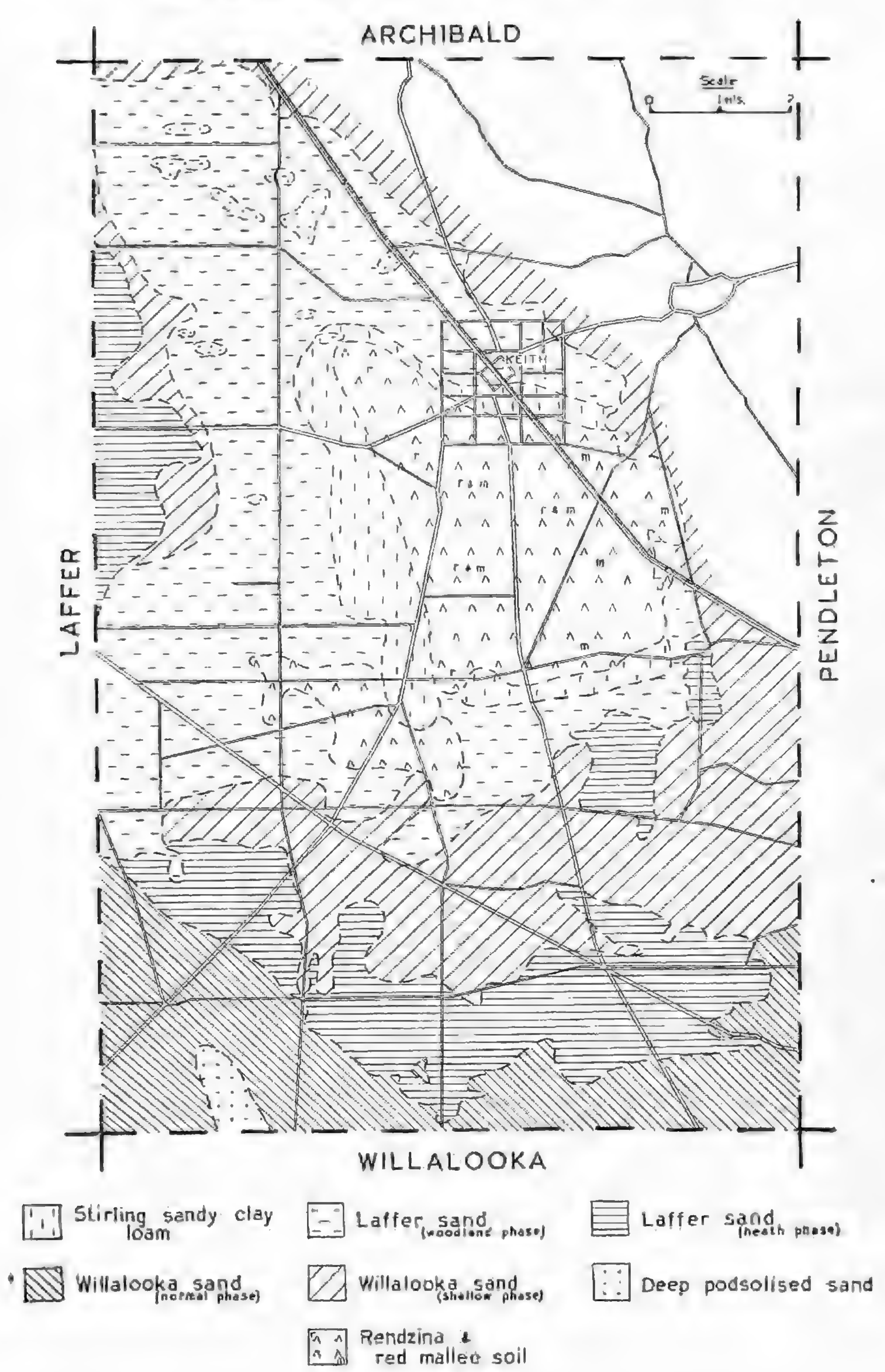
VEGETATION MAP OF THE HD. OF STIRLING



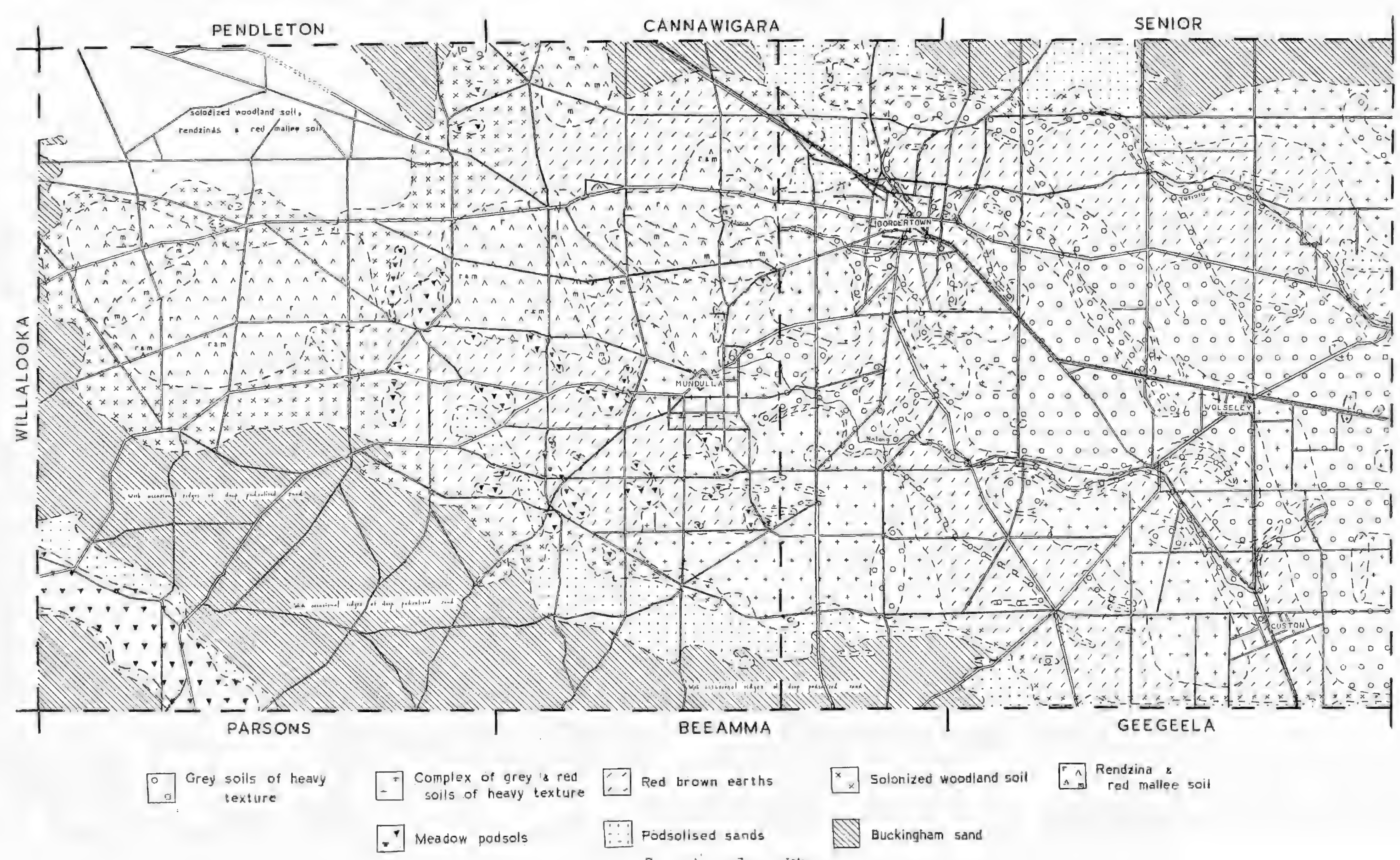
VEGETATION MAP OF THE HUNDREDS OF WIRREGA AND TATIARA



SOIL MAP OF THE HD. OF STIRLING



TENTATIVE SOIL MAP OF THE HUNDREDS OF WIRREGA AND TATIARA



	(1)	(2)	(3)	(4)	(5)	(6)	(7)
*Plantago lanceolata	—	—	x	—	—	—	—
*P. bellardii	x	—	—	x	—	—	—
*P. coronopus	x	x	—	x	—	—	—
*P. varia	—	x	—	—	—	—	—
Asperula scoparia	x	—	—	—	—	—	—
*Sherardia arvensis	x	—	—	—	—	—	—
Wahlenbergia gracilis	—	x	x	x	—	—	x
Lobelia pratioides	—	—	—	—	—	—	x
Pratia concolor	x	—	—	—	—	—	—
Goodenia robusta	—	—	—	—	x	x	—
G. heteromera	—	—	—	—	—	—	x
G. pinnatifida	x	—	—	—	—	—	—
Brachycome graminea	x	—	—	—	—	—	—
B. goniocarpa	—	—	—	—	x	—	—
Calotis cymbacantha	x	—	—	—	—	—	—
Vittadinia triloba	x	x	x	x	x	—	—
Centipeda minima	—	—	x	—	—	—	—
Cymbonotus lawsonianus	—	x	x	x	—	—	x
*Cryptostemma calendulaceum	x	x	x	x	x	x	x
Gnaphalium japonicum	—	—	—	—	—	x	—
Helipterum corymbiflorum	x	—	—	—	—	—	—
H. australe	—	x	—	—	—	—	—
H. pygmaeum	x	—	—	—	—	—	—
Helichrysum semipapposum var. brevifolium	x	—	—	—	—	—	—
H. apiculatum	—	x	x	—	—	x	—
Leptorhynchus squamatus	x	—	x	—	—	—	—
*Inula graveolens	—	—	x	—	—	—	—
Myriocephalus rhizocephalus	x	x	—	—	—	—	—
Angianthus strictus	x	—	—	—	—	—	—
Calocephalus citreus	x	—	x	—	—	—	—
Craspedia globosa	x	x	—	—	—	—	—
Craspedia uniflora	x	—	—	—	—	—	—
*Cirsium lanceolatum	x	x	—	—	x	x	x
*Carduus tenuiflorus	x	x	x	x	—	—	x
*Silybum marianum	—	—	x	—	—	—	—
*Ornopordon acaule	x	—	x	x	—	—	—
*Centaurea calcitrapa	—	—	x	x	x	x	—
*Carthamus lanatus	x	—	—	x	—	—	—
*C. glaucus	—	—	—	x	—	—	—
*Hedypnois cretica	x	—	x	x	—	—	x
*Hypochoeris radicata	—	x	x	x	x	x	x
*Taraxacum officinale	—	—	x	—	—	—	—
*Sonchus oleraceus	x	x	x	x	x	x	x

CALCAREOUS TUFA DEPOSITS IN NORTHERN NEW GUINEA

BY PAUL S. HOSSFELD

Summary

The widespread occurrence and formation today of calcareous tufa deposits in many of the torrential streams of the coastal ranges of northern New Guinea are described, also the features produced by these deposits. It is suggested that the severe dissection by those streams which at present are building up their channels was accomplished during a time when the climate exhibited a marked differentiation into wet and dry seasons. The advent of more evenly distributed precipitation resulted in the formation of numerous springs which, because of their very small catchment areas, are made permanent only by the almost daily rainfall.

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By PAUL S. HOSSFELD*

[Read 9 November 1950]

SUMMARY

The widespread occurrence and formation today of calcareous tufa deposits in many of the torrential streams of the coastal ranges of northern New Guinea are described, also the features produced by these deposits. It is suggested that the severe dissection by those streams which at present are building up their channels was accomplished during a time when the climate exhibited a marked differentiation into wet and dry seasons. The advent of more evenly distributed precipitation resulted in the formation of numerous springs which, because of their very small catchment areas, are made permanent only by the almost daily rainfall.

The climatic change may coincide with the termination, or recession from its maximum, of the Würm Glaciation.

The existence of tufa deposits in streams is a well-known feature of many limestone regions. The occurrence and formation today of such deposits in Northern New Guinea with its very high rainfall and steeply-graded juvenile drainage, appears to indicate recent climate changes.

In New Guinea the occurrence of tufa is widespread. It was observed by the author in the three deeply-dissected regions which form the mountainous hinterland of Madang, Aitape (Raggatt, 1928) and Vanimo respectively. All these areas are relatively close to the coast and the last two particularly are subject to a very high rainfall even in the so-called dry season, more correctly referred to as the "less wet" season.

Cainozoic limestones are plentiful in many areas. In others, richly fossiliferous mudstones and marls are the sources of the calcium carbonate. A small percentage of streams have their sources in igneous rocks or in sediments low in calcium carbonate. These do not exhibit tufa formation except in a minor degree where small springs or seepages occur. With very few exceptions, those streams, the sources of which are springs issuing from lime-bearing rocks such as limestones and calcareous sandstones and mudstones, are depositing tufa in their upper reaches.

These deposits are of several types. The commonest and most spectacular formation is the building up of masses of tufa at the lips and on the rock faces of waterfalls. It is well-known that in northern New Guinea the generally most practicable, and geologically the most profitable traverses are along the stream beds. The ascent of the numerous waterfalls encountered is impossible in many instances. In others the deposits of tufa provide a means of ascent which, however, may still be laborious and dangerous. The occurrence of tufa deposits on such features is surprising at first, but is so common that it is soon taken for granted.

This deposition of tufa on the lip and face of a waterfall has a two-fold effect. Not only does it prevent the normal recession of this erosion feature, but the gradual growth downstream of the deposit causes an advance of the

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waterfall and a gradual diminution downstream of its height until the end result is reached in the form of a regularly sloping ramp of tufa. It is considered probable that the angle of slope of the ramp is dependent on velocity and volume of water, amount of available calcium carbonate and the incidence of floods.

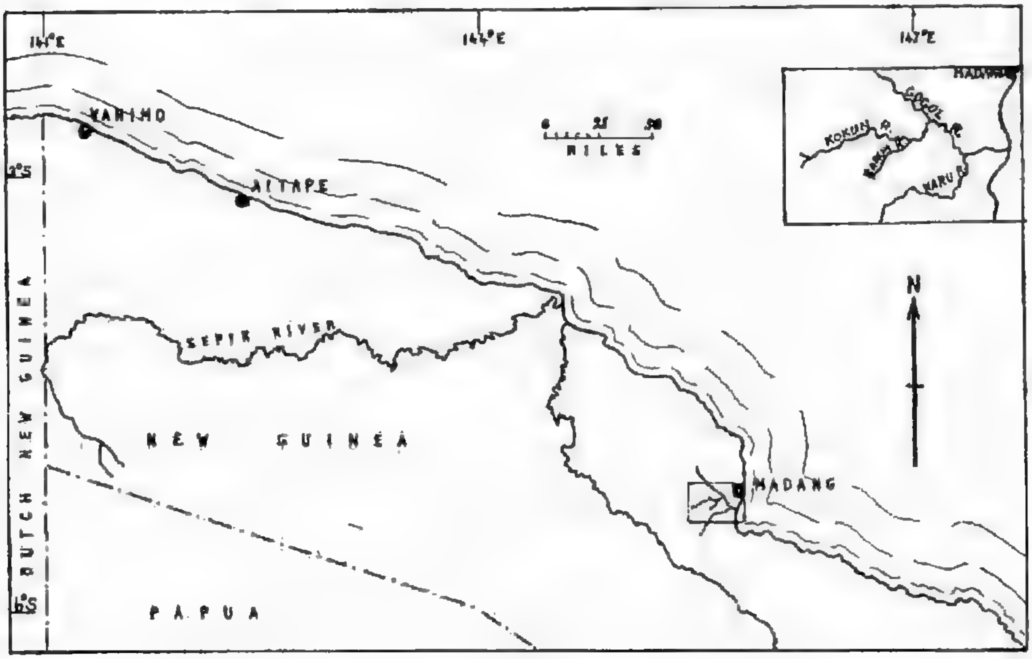

Fig. 1

Ramps of such origin were found in a number of instances. Most of them are covered by considerable volumes of water which, foaming over the rough surface, form a beautiful spectacle but cannot be traversed. Two instances were surveyed where the water enters near the top and issues at the foot of the deposit, thus forming a dry ramp (fig. 2). Only those who have had to force their way through trackless jungle for months or to spend week after week traversing and surveying running streams will appreciate the pleasure experienced in suddenly encountering a feature such as these dry ramps. They resemble a roadway, which though steep, gives a good grip because of its rough surface. For a short time it is possible to walk on a clean surface without stumbling over roots or hidden boulders or through morasses.

The two dry ramps were surveyed and both have a grade of approximately 1 in 3, or 18 degrees, but this may not be a constant figure for all such features. The longer ramp, occurring in a small tributary of the Barum River in the Madang district, has a length of 320 feet and follows the curve of the narrow gorge in which it occurs (fig. 2).

All stages were observed, from the thin surface coating of the lip and face of a waterfall to pendant growths of various shapes partly coalescing, and continuous masses from the top to the bottom of the stream channel, but showing a decrease in height downstream. Although the orderly growth downstream of these deposits is interrupted at times by the breaking off of large overhanging masses, the over-all result is the gradual building up downstream of these formations.

The final result of this constructive process is the elimination of waterfalls, and because of the resistance to stream flow by the rough surface of the tufa, a considerable reduction in velocity.

Another feature, noticeable particularly in, and confined probably to areas of extensive limestones is the formation of bars across the stream (Danes, 1910) (Cotton, 1941). Even where the grade is relatively steep, this produces a series of terraced pools at successively lower levels, each one discharging as a minute waterfall into the pool below.

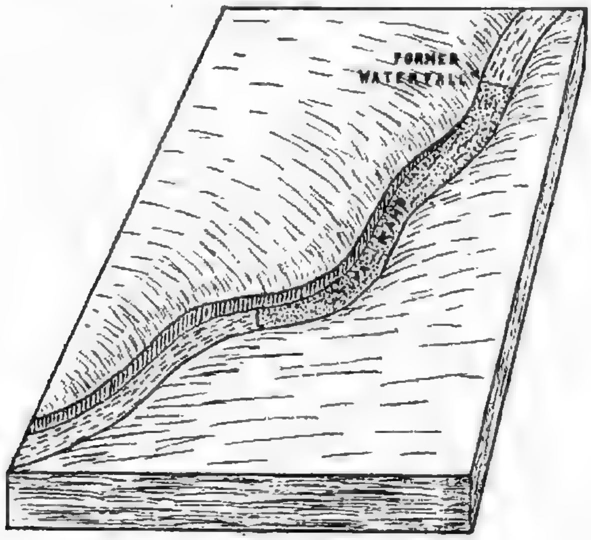

Fig. 2

The bars though naturally somewhat irregular, are curved, and convex downstream. Where well developed, they interlock to such an extent that they form an intricate and irregular pattern. These tufa bars are formed apparently where the stream cascaded over an obstruction such as a rocky bar or boulder or any other obstacle to its flow. In addition to checking the flow and reducing the erosive power of the stream to a negligible quantity, these pools are basins of deposition. The supply of detritus from the steep banks and also that brought down by floods, tends gradually to raise the floor and would eventually eliminate the pools. This tendency is assisted by the deposition of tufa between the detrital material thus rendering much of it immovable. However, as the deposition of material in the pool proceeds, so in many instances does the building up of the tufa bars.

In those reaches where pools are filled due to too great a supply of detrital material, the resulting irregular surface will ensure the formation of other bars and pools. The result of such processes is the gradual filling of the existing gorges. One of the best instances observed is that of the middle segment of the Daunda River. This river which discharges into the sea near Vanimo, derives its water from springs issuing from the coral limestones capping the dissected Omili Plateau (Fig. 3). This stream has a very steep gradient, parts of its gorge being inaccessible, but nevertheless, it has ceased eroding its channel and is engaged in filling its gorge by means of the terraced pools and the downstream growth of its waterfalls. The frequent floods which, owing to the small catchment area, are of short duration, appear to have little or no ability to remove the material built up during its periods

of normal flow. Such denial not only in the case of the Daunda River, but also in the very numerous instances observed in northern New Guinea, of the normal processes of erosion of juvenile streams, implies a relatively recent change of conditions. The widespread and varied occurrences of these constructive processes are such that changes in grade due to local diastrophism cannot be considered. Further, instances were observed of streams adjacent tc each other and with a similar history and development, but in which those which had no calcareous rocks near their source were actively deepening their channels while those which were fed by calcareous springs had ceased eroding and were building up their beds. The other change of environment which must be considered is that of climate and the possibility of the present cycle having been preceded immediately by one in which the incidence of rainfall was different from today.

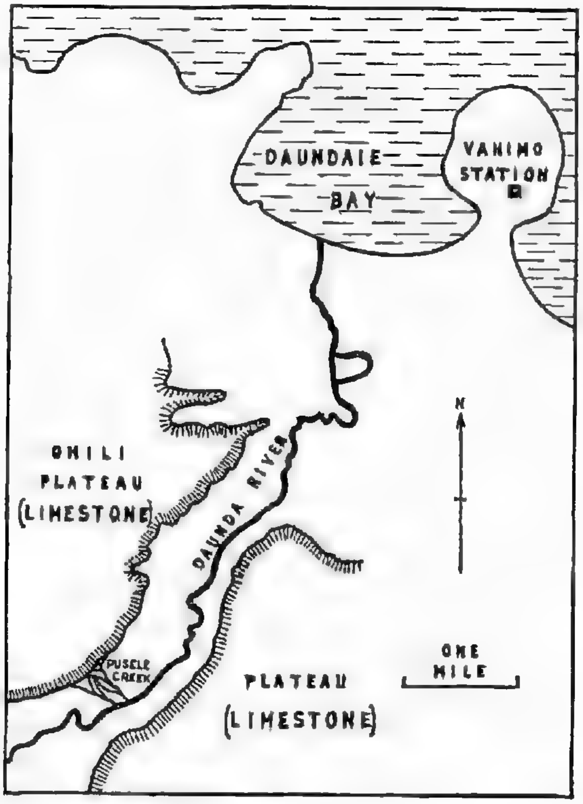

Fig. 3

The present climate is such that deposition of tufa proceeds at a faster rate than can be removed by erosion. Such erosion does not take place now during periods of normal flow, but is restricted to times of flooding. It might be contended therefore that an increase in the occurrence, duration and severity of floods would produce greater erosion and if such increase were sufficiently great, remove tufa deposits faster than they could be formed during the periods of normal flow, which obviously would be reduced greatly both in number and duration. However, the very high rainfall experienced in some of the areas examined, a rainfall so high that in some localities absence of rain for three days in the dry season was considered a drought, suggests that a much higher rainfall in recent times is improbable. It is a pos-

sibility, however, that such may have been the case, and the development of the deep gorges and intense dissection could be ascribed to such a wetter period, when the duration of normal flow and hence of tufa formation would be decreased and the times of severity of erosive processes increased considerably.

The other possibility, that the climate was drier, or that the rainfall was restricted to a definite season only, appears to be supported by more evidence.

It is obvious that the deposition of the tufa is dependent on springs charged with calcium carbonate. At present these springs appear to be permanent in the great majority of cases observed. There are some small springs which flow intermittently but these do not produce significant deposits. Any decrease in the amount or duration of flow of the springs would decrease the production of tufa.

The greater proportion of the springs which supply the headwaters of the various streams have very small catchment areas and are short-lived, depending for their permanence on the frequent and almost daily rains. Many of them cease to flow after two or three days without rain. A prolonged dry season would result in the cessation of flow in all except the larger streams which are supplied by deep-seated springs. There would then be no long-continued supply of calcareous spring water to build up the tufa deposits. Such small deposits as could be formed would tend to be removed during the periodical flooding of the streams. As stated above, there are very numerous examples of severe dissection and deep precipitous gorges where grades are still very high but active deepening has ceased. These features suggest therefore that such erosion took place when the climate was different from that of today in so far as it was divided much more sharply into wet and dry seasons and probably a smaller total annual precipitation, a climate similar to that of northern Australia today. Small isolated remnants of sclerophyll vegetation on exceptionally porous rocks such as limestones and gravel ridges, and surrounded by a luxuriant rain forest, support the belief that a prolonged dry season was a feature of the former climate. The discovery and survey by the author of the Pusele Creek supplies strong supporting evidence.

The Pusele Creek which flows into the Daunda River (fig. 3), has a total length of approximately 2,100 feet. Although short, this creek discharges a considerable volume of water. It has no direct catchment area and carries away only such of the rain as falls on it or the spaces between its distributaries. The creek is formed by several strong springs issuing at the foot of the limestone cliff which is the edge in this area of the Omili Plateau (Fig. 4). This plateau consists of coral limestone and is approximately at 2000 feet above sea-level.

These springs flow down a slope of approximately 9 degrees, which steepens rapidly to 18 degrees within the first 1500 feet and then becomes very much steeper until it reaches the top of the Daunda Gorge (Fig. 5). The springs unite, form distributaries and reunite to form a bewildering anastomosing pattern comparable to a river delta. This network exists, however, on the steep slopes referred to above, and what is more, this steep slope is itself a spur from which the surface drops relatively steeply on both sides (Fig. 6). The network of the Pusele Creek occupies therefore the steeply sloping crest of a spur. The Pusele Creek and its various distributaries have not excavated any channels or valley but represent a truly perched stream which flows at a level higher than the adjacent surface. This is pos-

sible only because deposits of tufa form the walls or miniature levees which hold the various streams in position but do not prevent partial spilling over from time to time and therefore changes in the pattern. That the tufa deposits are not capable permanently of retaining this perched stream in its unstable position is shown by the existence of three channels which have found their way to a lower stream to the south-west. It is clear that once

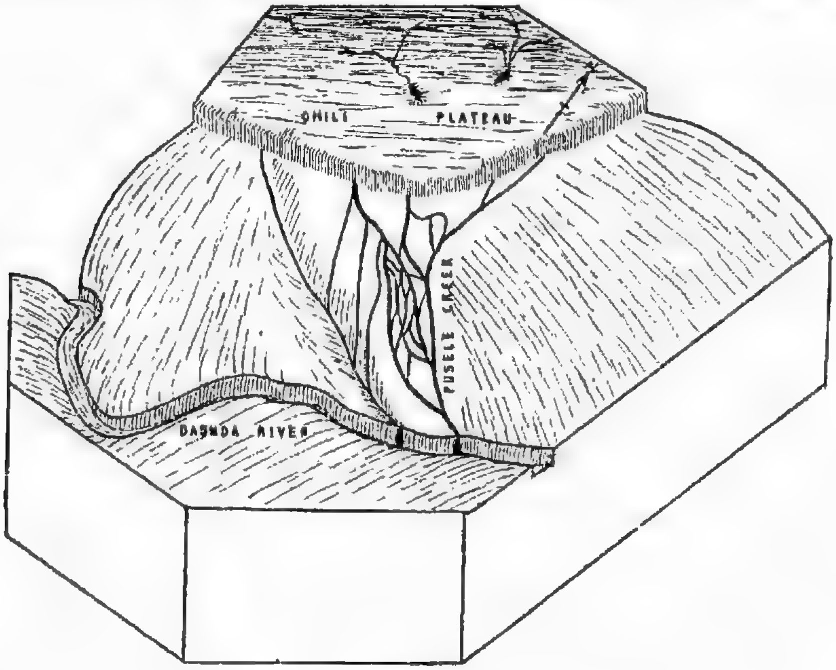

Fig. 4

such a new stream course is established it will remain, and eventually the whole of the Pusele Creek will be diverted to the lower levels adjacent to the spur. It is obvious that if a period of greater rainfall had preceded the present cycle then such capture would have taken place more speedily and the Pusele Creek, had it existed then, would have had a short life only. If, however, a climatic cycle with prolonged dry seasons preceded that of today,

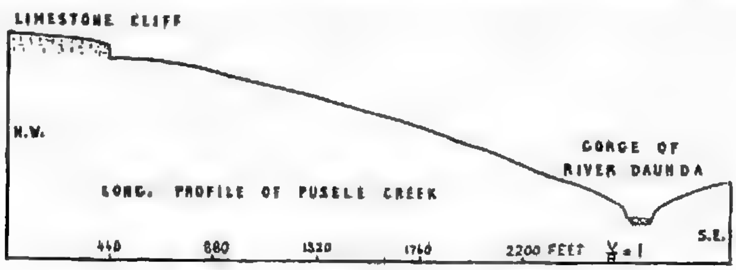

Fig. 5

then springs would be non-existent or flow for very short periods only and no creek would exist where the Pusele flows today. A change to the present climate, a gradual growth in volume and duration of the present springs would produce gradually the tufa-bordered channels with their intricate network of intersecting channels.

It might be suggested that recent fault block movements were responsible for the elevation of the limestone and the development of the springs. The limestone is part of a large, formerly very extensive, high level area of coral limestone. There is no doubt that the region owes its dissection and the severity of its topography to such elevation. This occurred, however, at a time far enough distant to permit of the dissection of the region. Events such as cessation of erosion because of tufa deposition are of later date and obviously caused by climatic changes.

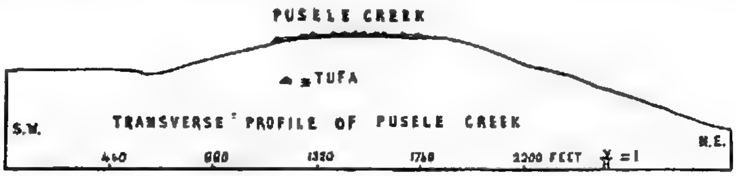

Fig. 6

The observed features suggest therefore that, until relatively recent times, the climate of northern New Guinea had been one of marked division into wet and dry seasons and that because such a sharp differentiation no longer exists, deposition of calcareous tufa by permanent and semi-permanent springs is not only checking erosion but is also filling up the gorges excavated during the former cycle.

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THE ARCHEAN COMPLEX AT HOUGHTON, SOUTH AUSTRALIA

BY ALAN H. SPRY

Summary

This paper deals with the petrology of a group of Archaean rocks near Houghton, South Australia. The complex consists of a range of highly metamorphosed sediments ranging in character from schists and gneisses to rocks resembling altered acid and intermediate igneous types. The most abundant rock is a coarse augen gneiss which frequently contains sillimanite or garnet. This has resulted from high-grade regional metamorphism and potash metasomatism on an argillite followed by marked retrograde metamorphism.

THE ARCHEAN COMPLEX AT HOUGHTON, SOUTH AUSTRALIA

By Alan H. Spry *

[Read 9 November 1950]

SUMMARY

This paper deals with the petrology of a group of Archean rocks near Houghton, South Australia. The complex consists of a range of highly metamorphosed sediments ranging in character from schists and gneisses to rocks resembling altered acid and intermediate igneous types. The most abundant rock is a coarse augen gneiss which frequently contains sillimanite or garnet. This has resulted from high-grade regional metamorphism and potash metasomatism on an argillite followed by marked retrograde metamorphism.

The rocks of igneous appearance which have been called the "Houghton Diorites" are granulites derived from lime-magnesia rich sediments by high-grade regional metamorphism combined with potash and soda metasomatism. Some sandstones have been feldspathized, giving rise to white feldspar rich rocks for which the term leucocrat or leucocratic granulite has been used to replace Benson's term "gneissic aplite". There are notable amounts of phyllonitic schists which have been formed from both gneisses and granulites by retrograde metamorphism. The migmatitic complex was closely folded during the Archean, and overlain unconformably by sediments in Late Proterozoic times.

The Archean rocks occupy the core of a slightly overturned anticline of Lower Palaeozoic age. The schistosity in both the Archean and Proterozoic rocks is generally parallel to the axial plane of this fold. The area was peneplained, and then block faulted in the Tertiary.

LOCATION

The area is situated to the north and east of the town of Houghton, which is twelve miles east of Adelaide, in the Mount Lofty Ranges. The Archean inlier is roughly lenticular in shape, being 16 miles long in a northerly direction and five miles east-west at its widest part. It extends from Castambul to Chain of Ponds on the River Torrens, northwards through the Humbug Scrub to a point west of the Barossa Reservoir.

PREVIOUS INVESTIGATIONS

The accessibility and economic prospects of these crystalline rocks have led to their investigation by a number of writers. The occurrence of gneisses, believed to be possibly Silurian, in the Humbug Scrub was mentioned by Brown and Woodward (1885). A further brief mention of the same rocks was made by Howchin (1906), who related them to the Archean. Benson (1909) carried out a detailed study of the rocks near Houghton, and described those banded crystalline rocks which have a chemical composition resembling an igneous rock as the "Houghton diorite". He believed them to be of igneous origin, formed by intrusion of the "Houghton Magma". He refers to them as being Algonkian in age.

England (1935) demonstrated the chemical similarity of rocks from various parts of the State, believed to be of Archean age. It is unfortunate that this work was of a petrographic nature on more or less unrelated specimens and not supported by detailed field work. Hossfeld (1935) discussed briefly the Humbug Scrub gneisses, and stated that "the sedimentary nature of most of these rocks

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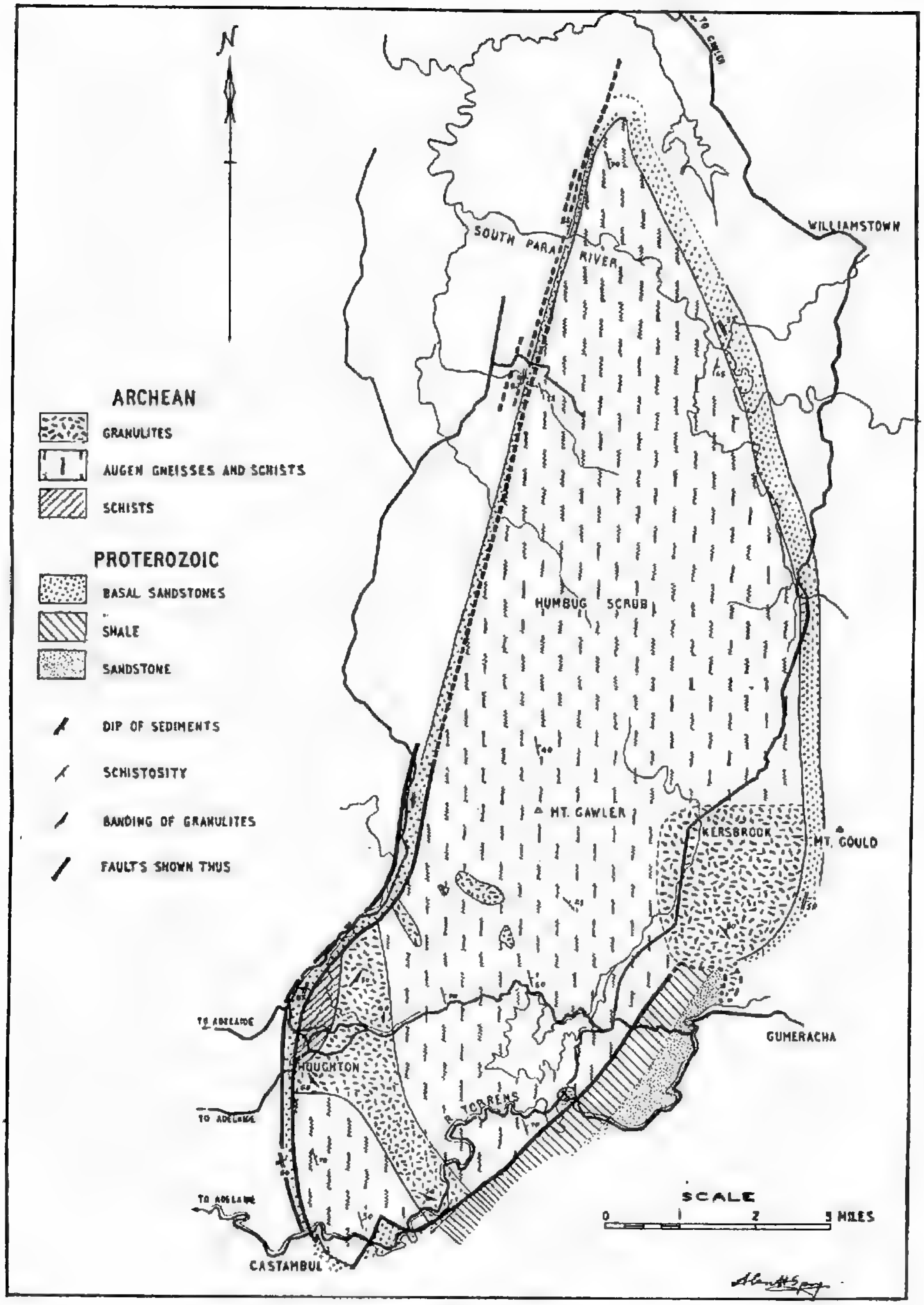

Fig. 1
A regional map showing the extent of the Archean inlier.

is evident. The only important exceptions to this are certain areas of gneisses in the Humbug Scrub". He mentioned a contact between the gneisses and injected schists and believed "that the augen gneisses may represent an altered igneous intrusion changed partly while still in the plastic condition." Alderman (1938) made an important contribution to the study of the gneiss and removed any doubt of their sedimentary nature by showing that the two rock types mentioned above by Hossfeld are chemically and microscopically similar. However, he postulated a mechanism for the formation of the augen gneiss by the injection of a sodium silicate fluid along the schistosity of the phyllites. Sprigg (1945) and (1946) dealt extensively with the geomorphology and structure of this area as part of the Mount Lofty Ranges, but some details of structure are now being revised. In a preliminary survey for the South Para Dam site, Miles (1950) contributed a detailed map of the portion of the unconformity together with some structural data.

SCOPE OF PRESENT INVESTIGATION

The position in 1949 was that, although all geologists familiar with the "diorite" doubted its igneous origin, the published work required considerable revision in view of the rapid advances in geological knowledge in recent years. With this end in view, work was commenced early in 1949 and completed late in 1950.

Extensive field work was undertaken and the Archean inlier was mapped in detail as a whole. This has revealed a complex consisting of schists and gneisses already accepted as being of a sedimentary derivation, with some rocks which have been considered magmatic in origin and called diorites, but which are also highly altered sediments. There is widespread evidence of high-grade regional metamorphism, although many of its effects have been modified by later retrograde metamorphism. Further complexities are introduced due to metasomatism and by metamorphic convergence of the Archean gneisses and the sheared basal members of the Adelaide System.

This investigation has been particularly concerned with the genesis of the "Houghton diorite" which is shown to be a metamorphosed sediment. In this paper the term granulite is recommended, and used in place of "diorite" because of the unsuitability of the latter term to express the true nature of the rock.

STRATIGRAPHY

The area contains rocks of the Archean, Late Proterozoic and Tertiary age with no evidence of deposition for long periods between them.

There was considerable erosion of the Archean rocks before the sediments of the Adelaide System were deposited with marked unconformity upon them. Although this contact is frequently obscured by shearing or soil cover, there are exposures at the following places (in addition to those recorded by Miles (1950):

(a) In a creek-bed south of the road from One Tree Hill to the Humbug Scrub Sanctuary. The actual erosion surface is seen to be overturned and dips east at about 80°, being stratigraphically overlain by 150 feet of basal arkoses.

(b) At the Devil's Nose on the South Para River the unconformity is normal and dips steeply west.

(c) On the east side of the Archean inlier near the junction of the Kersbrook-Williamstown road and the track to the New Deloraine Mine, gneisses are overlain by ilmenitic sandstones with a Mount Bessemer type haematite-schist notable, dipping at about 60° to the east.

Due to Palaeozoic and Tertiary faulting and soil cover at the north and south of the inlier it is not possible to find a direct connection between the ilmenitic sandstones and arkoses to the east and west of the inlier, and Hossfeld (1935) assumed that these beds were of different ages. However, in view of the strong lithological similarities of the sediments on either side of the Archean, there is no evidence that the basal beds to the east of the inlier are not the same age as those to the west. Strike faults have disturbed the stratigraphic succession above the Archean and correlation is possible only in the lowest members.

There is no evidence of sedimentary deposition over the folded Adelaide System until mid-Tertiary, when horizontal lateritic gravels of a terrestrial nature were deposited unconformably upon both Archean and Proterozoic rocks. After later block-uplifts these ferruginous conglomerates remain as small but persistent patches, usually capping hills.

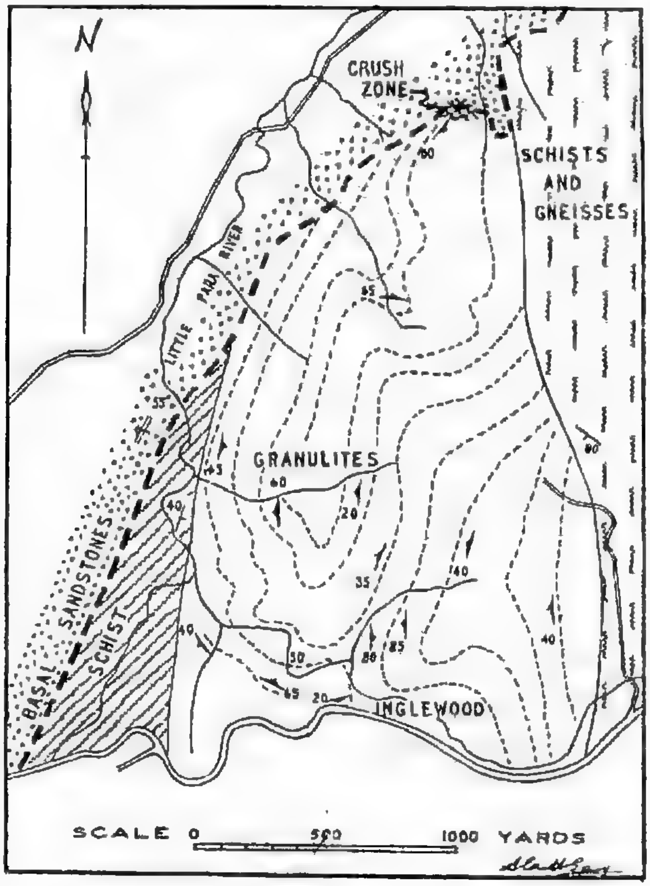

Fig. 2

A diagrammatic sketch map illustrating the manner folding of the granulites.

STRUCTURE

The production of structures at various periods over the whole range of geologic time from Archean to Tertiary, gives the area such an involved history that the problem as revealed in the field is clearer when dealt with on a chronological basis.

Archean Orogeny

The oldest orogenic structures are those ptygmatic folds of the highly metamorphosed Archean sediments. Field observations of the granulites show folding which is complex but which may be mapped. Poor exposures and the superimposed schistosity, however, tend to obscure the tight isoclinal folds in the gneisses. These latter folds are only revealed to any extent in the fresh vertical rock-faces along the Torrens Gorge. The scale of folding differs considerably in the gneisses and granulites. There are numerous small isoclinal folds with steeply dipping limbs in the gneisses, but quite large folds in the order of hundreds of yards across with relatively gently dipping limbs in the granulites.

The banding in the granulites may be treated as bedding and can be mapped similarly to a normal sediment. Fig. 2 shows a generalized picture of the structure of the granulites north of Houghton and Inglewood. It is not possible to show more than structural trend-lines as exposures in the field are poor, and discontinuous overturning of the beds in places has produced a complex fold system.

There are a series of faults in the metamorphic rocks which are attributed to the Archean but which differ in age within that period. The order of formation is suggested by the magnitude and kind of mineralization of the fault zones. The earliest and smallest faults are tightly closed and cut tiny ptygmatic drag folds, while the next to form are larger and are marked by ilmenite veins up to six inches across. The last faults to form are largest and the minerals introduced were quartz and tourmaline. It appears that after the peak of metamorphism had passed, conditions favoured fracture rather than flow and the rocks were faulted rather than folded as previously, with the size of the faults increasing as cooling became advanced.

Palaeozoic Orogeny

The most pronounced regional structure of the Archean rocks is the schistosity, which is highly developed in the gneisses but only sparsely in the granulites. This schistosity is produced by parallelism of sericite flakes which were formed by the retrograde metamorphism of the feldspars of the gneisses. It shows a marked regularity over a wide area and almost invariably strikes at about 170° and dips steeply east. At various places, particularly west of Mount Gawler, cross folding has caused the strike to swing sharply round, but these variations are only subsidiary to the general trend. This schistosity is often almost parallel to the axes of Archean folds but its direction is controlled by a major anticline in the gneisses formed in post Adelaide-System time. After the deposition of the Late Proterozoic sediments, there was a great period of orogeny when the Adelaide System was extensively folded and faulted. This upheaval has been considered to have occurred during the Cambrian but is here classed only as Lower Palaeozoic. During this period there was not only considerable folding of the normal kinds in the Proterozoic sediments but also the gneisses were thrown up into a great anticline, overturned in part slightly to the west. This is demonstrated by the normal, moderately dipping unconformity on the east of the inlier, with a steeply dipping, frequently overturned contact to the west. A diagrammatic sketch section is shown in fig. 3. The regional schistosity of the gneisses is parallel to the axial plane of this fold and also to the schistosity in the Adelaide System and is evidently controlled by this period of folding. If the schistosity of the gneisses had been formed previously to this period then it would have shared in the folding and would show the form of a schistosity anticline instead of being in a regular regional direction.

In certain places on the western side, the basal arkoses have moved considerably over the Archean basement, with the result that the junction has been obscured due to a pseudoconformity between the older gneisses and the sheared Proterozoic sediments. Metamorphic convergence between the rocks of different age has caused the exact margin to become indefinite. This phenomenon is well shown on the hill south of the Torrens River at Castambul, and at a point approximately two miles north-east of Houghton near the Lower Hermitage Road.

The direction of the schistosity of the gneisses is attributed to Lower Palaeozoic orogenesis but the mineralogical changes of the retrograde metamorphism may have taken place before the deposition of the Adelaide System. This is indicated by the fact that marked retrograde effects cease sharply where an unsheared unconformity can be found and the basal arkoses do not share the breakdown.

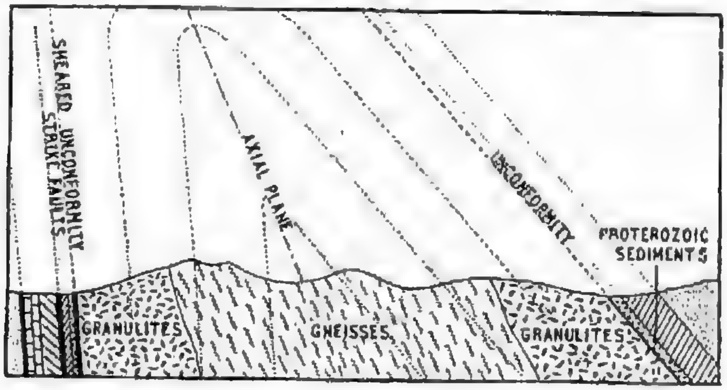

Fig. 3
A purely diagrammatic section indicating the general structure in the Archean due to Palaeozoic folding.

Apart from the complex shears of this time, there are the simpler faults and crush zones which are mineralized with quartz. About one mile north-west of Gumeracha there is a crush zone approximately half a mile across in which Archean granulites and schists, together with Proterozoic phyllites, sandstone and dolomite, become slightly contorted. A little mineralization has occurred as shown by the presence of quartz, calcite, pyrites and gold. The formation of the major anticline which caused considerable slip along the western margin of the Archean inlier, also resulted in a series of parallel strike faults in the Proterozoic sediments close to the inlier. The major fault in the south-east of the area is considered by Sprigg (personal communication) to be a Palaeozoic fault re-opened in Tertiary times.

Just within the southern margin of the Archean are outliers of Adelaide System sandstone, quartzite and Lower Torrens dolomite, but these are so poorly exposed that it is not possible to determine conclusively whether they are simply residual patches left by erosion or are the remains of a thrust sheet from the south-east.

Tertiary Orogeny

The last stage in the orogenic history is revealed by the fractures of the Tertiary which appear as numerous fresh unmineralized faults, sometimes of extremely large dimensions.

These faults show moderately well-dissected scarps. Certain faults show mineralization (typical of Palaeozoic movement), together with a scarp (typical of the Tertiary block uplifts). It is considered that such faults originated in the Palaeozoic and were re-opened in the Tertiary.

The striking similarity in the field of the direction of all structural features points to a regularity in the direction of the orogenic forces in the geosynclinal basin from Archean to Tertiary times.

SEDIMENTS OF THE ADELAIDE SYSTEM

The Late Proterozoic sediments of the Adelaide System overlie the Archean with marked unconformity. At the base are grits and arkoses notable because of cross-bedding shown by ilmenite. In this area, these sediments only show slight metamorphism in certain localities where they become sheared.

A typical example of the lowest part of the series is shown at locality (a) on page 117. The series is as follows:—

150 feet. *Basal Grits.* These include a coarse, black arkosic quartzite at the bottom, then a white arkose and white cross-bedded ilmenitic sandstones and grits, slightly overturned.

400 feet. *Phyllite.* A dark micaceous phyllite with some arenaceous and calcareous bands dipping vertically. A Palaeozoic strike fault occurs here.

180 feet. *Dolomite* A dark blue fine-grained rock, possibly equivalent to the Upper Torrens dolomite. The dip becomes shallower to 50° E.

100 feet +. *Sandstone and Phyllite.* White sandstone and grey phyllite are cut off by a large strike fault.

The basal sandstones are typified by the presence of feldspar and ilmenite and when sheared these minerals form sericite and chlorite, making the rocks schistose. This process gives rise to low-grade schists at the unconformity and these sheared basal Adelaide System rocks become very difficult to distinguish from the Archean schists.

Rock (8933) is typical of these schists. It is a light-coloured highly schistose rock consisting of sericite with bands and patches of green mica, the bands being at about 30° to the schistosity. It has a slightly speckled appearance due to the presence of ilmenite.

Microscopically it differs from the retrograded Archean gneisses in that the sheared nature is evident and plagioclase relics are lacking. Quartz is abundant and cracks in it are often filled with sericite in parallel flakes. Leucoxene is common, while chlorite is present as wisps and patches.

This metamorphic convergence causes the Archean and Proterozoic rocks to become similar in appearance and thus causes difficulty in field mapping in certain parts of the area. The southern part of the western margin is particularly obscure for this reason.

ARCHEAN ROCKS

The Archean rocks are classified under two major divisions, the augen gneisses and the granulites. Both types have associated schists which have formed by retrograde metamorphism. There is a further minor group referred to as the transition gneisses which forms an intermediate step between the gneisses and granulites. The remainder of the rocks are discussed as pegmatites or unclassified types.

(a) Gneisses
(b) Granulites and leucocrats
(c) Transition gneisses
(d) Pegmatites and pegmatoid rocks
(e) Unclassified types

GNEISSES

The "Humbug Scrub gneisses" are the predominating type in the area, and together with their associated schists constitute about 85% of the Archean. They are rocks with light-coloured quartzo-feldspathic bands or augen set in a dark schistose ground mass of sericite and quartz, and are classified in the field as banded gneisses and augen gneisses respectively.

The banded and augen varieties merge into each other and Alderman (1938) has shown them to be chemically similar. In the field the gneisses appear to have bands and augen of pegmatitic material which have been forced along the schistosity of the sericite schists. On this basis the gneisses were considered by Alderman to be injected types. Further investigation now shows that the schistosity of the gneisses was formed later than the process of introduction, and that the schists now present are the final result of a complex process and are not the source rocks of the gneisses.

Mineralogically the gneisses consist of microcline with variable amounts of quartz, much fine sericite (with chlorite and biotite) and only minor amounts of plagioclase. In addition, sillimanite and garnet occur where the original grade of metamorphism was sufficiently high and where retrograde effects have not obscured them. The gneisses outcropping in the southern parts of the area usually carry one or both of these index minerals or at least show pseudomorphs of them. These high-grade minerals do not occur north of the latitude of Kersbrook and the isograd is apparently there.

Typical examples of gneisses taken from widely-spaced areas indicate the nature and variations within this group.

Rock 8938, from Castambul, is a typical example of the gneisses of the Lower Torrens Gorge which have reached the biotite grade only. It is a light grey gneiss, irregular and coarse in grain, with large feldspar phenoblasts up to 3 cms. diam., and smaller quartz crystals enclosed in a fine-grained micaceous mass of sericite and chlorite. The feldspar is chiefly fresh microcline with a little much-altered plagioclase (Ab_{98}).

The alteration of the feldspars, which is invariably well advanced, has taken place firstly along cracks and cleavages, and finally large areas are made over to an aggregate of decomposition products. The process has given rise to small colourless granules of epidote or to a multitude of tiny colourless sericitic mica flakes, frequently orientated parallel to the twin planes of the albite. The size of these crystals does not permit the optical properties of the mica to be determined but it is presumed to be a potash variety. It may possibly be the soda-mica paragonite, but as albite appears to be stable under such metamorphic conditions and forms merely small clear untwinned grains under even the most severe stress, such does not seem likely. The potash necessary for the production of sericite within the plagioclase appears to have been held in an unstable solid solution and has been liberated under stress conditions. In some cases the plagioclase shows alteration around the edges, suggesting an attack by potash liberated when nearby crystals of microcline were sericitized.

In the more highly retrograded rocks the plagioclase is replaced progressively by increasing amounts of sericite until there is only a faint skeleton showing multiple twinning in a highly orientated mesh of fine sericite laths.

The potash feldspar which is present in abundance is invariably microcline and careful search showed no trace of orthoclase. Cross hatching is frequently visible, but even those crystals not showing this feature were found to be triclinic by orientation procedure on the Universal Stage. The feldspar is often perthitic (see Pl. VIII, Fig. 1) and contains large amounts of albite as coarse irregular spindles. It appears to be due to an exsolution process from a high-

temperature feldspar. Extinction angles from the 010 cleavage do not exceed 12°. It is noticeable in the hand specimen that the microcline is white while the plagioclase is flesh-coloured.

Quartz is abundant in all the augen gneisses and occurs as irregular, often elongated or lenticular crystals showing marked undulose extinction. It is frequently biaxial with a low optic axial angle. The undulose extinction of the quartz is very well developed and gives an erroneous impression of the amount of shearing which has taken place. One particular quartz crystal showed a difference of 60° in the extinction positions of its parts by rotation on the stage of the normal petrographic microscope, but on orientation on the Universal Stage it was found that all the optic axes in that crystal were parallel, indicating that the crystal lattice had not been appreciably strained. It has been shown by Sander (1930) that a quartz crystal in a sheared rock may have differences in the directions of its optic axes of up to 10°, and it is therefore presumed here that the metamorphism which has produced such striking features as the strong undulose extinction in quartz, the biaxiality in quartz and apatite, and a notable schistosity, has not been as high in shearing stress as is suggested by early observations. It is an additional fact that Reynolds (1936) has described similar features in other rocks, as replacement effects. All available evidence points to large-scale breakdown of the gneisses by *retrograde* metamorphism to a low-grade regional facies rather than a process of dynamic metamorphism producing sheared rocks.

In some cases the undulose extinction of the quartz appears to be due to the recrystallization and welding of several previously unrelated fragments tending to produce a larger crystal (super-individual) of uniform nature, and evidence often suggests a growth in the quartz rather than a fragmentation. There are examples of true sheared and mylonitized rocks where dynamic stresses have been high.

Biotite is present in this gneiss as very ragged laths and often as intimate growths with sericite and chlorite. Ilmenite crystals have been fractured, and in places iron appears to have been released to form a dark mica as a zone about the iron ore in a general matrix of sericite.

The schistose portion contains much sericite with biotite, chlorite, ilmenite, while the accessories are apatite, calcite, zircon and rutile.

In the upper reaches of the Torrens Gorge there are sillimanite and garnet gneisses. A typical specimen is (8928), a dark-grey rock, massive to gneissic in texture, with some silky white fibres of sillimanite, small green patches of chlorite which are pseudomorphic after garnet, and a scattering of pyrites. The rock possesses the common gneissic texture with large stressed and broken porphyroblasts of quartz and microcline in a well-directed schistose matrix. Sillimanite is present as fresh tabular crystals or in all stages of sericitization. Optically it is biaxially positive with a low optic axial angle (as low as 5°). The retrograde process of sericitization of high-grade sillimanite causes the geographical limits of the sillimanite zone to be very indefinite in the field. In some gneisses, well inside the sillimanite area, there are pseudomorphs which retain sufficient of the original form to allow it to be recognised, but frequently there is a complete obliteration of all high-grade minerals. The production of sericite from sillimanite is presumed to be concurrent with the sericitization of the feldspars, and is due to the excess potash liberated by the latter process under low-grade conditions.

A red-brown garnet, apparently near almandine in composition, is less abundant. Diapthoresis affects it to a lesser extent than the sillimanite, but it frequently shows partial or complete chloritization to a green penninite. The chlorite pseudomorphs are frequently visible in the hand specimen. It is noticeable that sillimanite and garnet occur together in the Torrens Gorge, but that

garnet alone occurs in the vicinity of Kersbrook. This suggests a series of sillimanite-, garnet-, and biotite zones towards the north, although the limits cannot be accurately delineated in the field.

The biotite has an appearance typical of high-grade Archean rocks in South Australia and occurs in irregular laths, often bent and strongly pleochroic from a light to a very dark brown. It is frequently riddled with small inclusions of iron ore or rutile, while in certain specimens it is found interleaved with sericite, chlorite, quartz or sillimanite.

Pyrites and zircon are accessory minerals. The zircon invariably shows a perfectly rounded or oval form which is considered to have been due to its original detrital origin, unaltered by later recrystallization. This form of zircon occurs in gneisses, schists and granulite alike.

Slight variations in the constituents of the gneisses are found, some being richer in sillimanite or garnet than others, and some lacking one or both of these index minerals.

Apatite is a common accessory in the gneisses, and a wide variation in properties is recorded. It may be colourless or pale brown, with a pleochroism $\epsilon > \omega$, and has an optic axial angle varying from 0° to 40°.

Associated with these gneisses are bands, lenses and large irregular areas of light- to dark-green schists, and these are considered to be the ultimate products of the retrograde processes. The schists possess the fine-grained sericitic directed texture of the gneisses, but lack the large feldspar porphyroblasts. They are very schistose and are considered to be the more highly retrograded members of the augen-gneiss group and are regarded as being *phyllonitic*, not *phyllitic* in nature. For a correct interpretation of the genesis of the rocks, it is necessary to recognise that there are no simple low-grade rocks within the Archean inlier.

Rock (8931) from the Torrens Gorge is typical of this group. It is a pale green schist of phyllitic appearance with both a banding and a strong cleavage. It is very schistose, consisting of a fine-grained aggregate of flakes of sericite with chlorite and quartz. The latter shows granulation and recrystallization in lenticular groups, elongated in the direction of the schistosity. Colourless sericite and chlorite may flow around small porphyroblasts of quartz or may grow in sheafs athwart the fissile direction. A string of rutile grains also cuts across the schistosity, apatite is accessory.

The schists show their true nature by their association in the field. Irregular bands up to hundreds of yards in width can be seen in direct contact with high-grade metamorphic rocks, *e.g.*, sillimanite gneisses. Schists in other parts of the area which appear to be phyllites are identical with these phyllonites.

From a detailed examination, the genesis of the gneisses appears both indefinite and complex, for nowhere in the area does there occur a rock which may be regarded as an unaltered parent type.

As far as can be ascertained the original rocks were pelitic. They underwent regional metamorphism which reached its maximum in the south where sillimanite-grade rocks occur, while rocks of the garnet and biotite grades occur to the north. At conditions of high temperature and pressure an introduction of alkalies (chiefly potash with less soda) took place. This resulted in the formation of soda-microcline which later unmixed to form a typical coarse high-temperature perthite. This introduction is considered to have been a "soaking" process with gentle addition and migration of material along previously existing S-planes. The lack of cross-cutting feldspathic bands and the general uniformity point to a gradual addition rather than a lit-par-lit "squirting" or injection. It seems most likely that the microcline was not introduced as such but was formed along preferred directions where fluxing and recrystallization took place. Orogenesis

caused tight isoclinal folding while the rocks were still in the plastic "migmatic" state. At a later stage, conditions of low-grade regional metamorphism with low temperature and strong shearing caused a period of retrograde metamorphism which affected the high-grade rocks considerably. It was at this time that the widespread regional schistosity now visible was produced by the alteration of microcline to sericite. Sillimanite became unstable and combined with the liberated potash to form sericite, while garnet was a little less unstable and usually became only partly chloritized. The biotite became a less ferruginous variety and deposited tiny granules of iron ore. The process was by no means uniform and affected certain areas to a greater degree than others. In some rocks no traces of original high-grade minerals remain, while in others only slight retrograde effects are noticeable. The effects of retrograde metamorphism have been arrested in all stages and the outlines of the process may be described briefly as a sequence.

(a) Early results are the cracking and bending of feldspar and biotite crystals accompanied by a little sericitization around the edges of microcline and sillimanite. Quartz shows undulose extinction.

(b) At a later stage, the general grain-size is smaller and the very large porphyroblasts have been broken up. The processes of sericitization, saussuritization and chloritization are well advanced. Cracks, cavities and cleavages are filled with alteration products. Quartz and apatite are biaxial.

(c) Still later the grain-size is smaller and more uniform, the largest porphyroblasts being quartz, elongated due to flow and recrystallization and with an optic axial angle of 5°. The high-grade minerals, microcline, plagioclase, sillimanite and garnet may still persist as vague relics. The rock consists for the most part of finely-schistose sericite, chlorite and biotite, with clear granules of quartz and regenerated albite.

(d) The final stage is that of the completely retrograde schists where no high-grade minerals occur and only tiny porphyroblasts of ragged quartz occur.

GRANULITES

In the south-western and south-eastern portions of the area around the towns of Houghton and Kersbrook respectively, there occurs a group of distinctive strongly-banded crystalline rocks rich in feldspar. Examples of these have been called the "Houghton Diorite" by Benson (1909) and they were thought to have been formed by the metamorphism of igneous rocks crystallized from the "Houghton Magma". There has been some doubt in the past as to the origin of these rocks, and although they constitute only 15% of the Archean rocks outcropping, particular attention has been paid to them.

On normally weathered faces of the flaggy slabs the appearance is often that of a normal sedimentary rock of quartzitic composition, and only on inspection of a freshly-broken face does the crystalline nature become apparent. The banding, which is a strongly-developed and typical feature is remarkable for its uniformity and parallelism. Bands vary in width from ¼"-3" and may be followed for 20 feet without significant variation, this being the longest unbroken rock face found (see Pl. VII, Fig. 2). This foliation is due partly to the segregation of coloured minerals (diopside, actinolite, ilmenite and epidote) in the darker bands, with quartz and feldspar in the lighter portions, and partly to the fact that retrograde metamorphism is more advanced in the latter. The banding is considered to be mimetic after original sedimentary banding and sometimes shows structures resembling cross bedding.

The granulites resemble igneous rocks in their chemical composition, and different varieties have been described as being of dioritic, syenitic or granitic nature. The extreme variability of composition from acid to intermediate is a typical feature and the varieties are intimately associated in the field. The most common rock is a plagioclase-rich quartz-poor granulite with the composition of a diorite, and this constitutes the major part of both the Houghton and Kersbrook bodies. Smaller masses of quartz-rich granulites occur in the Torrens Gorge. The smaller isolated bodies differ from the main masses and outcrop (1) on the map (Fig. 4) is chiefly a coarse quartz-feldspar-biotite-gneiss which is cut by

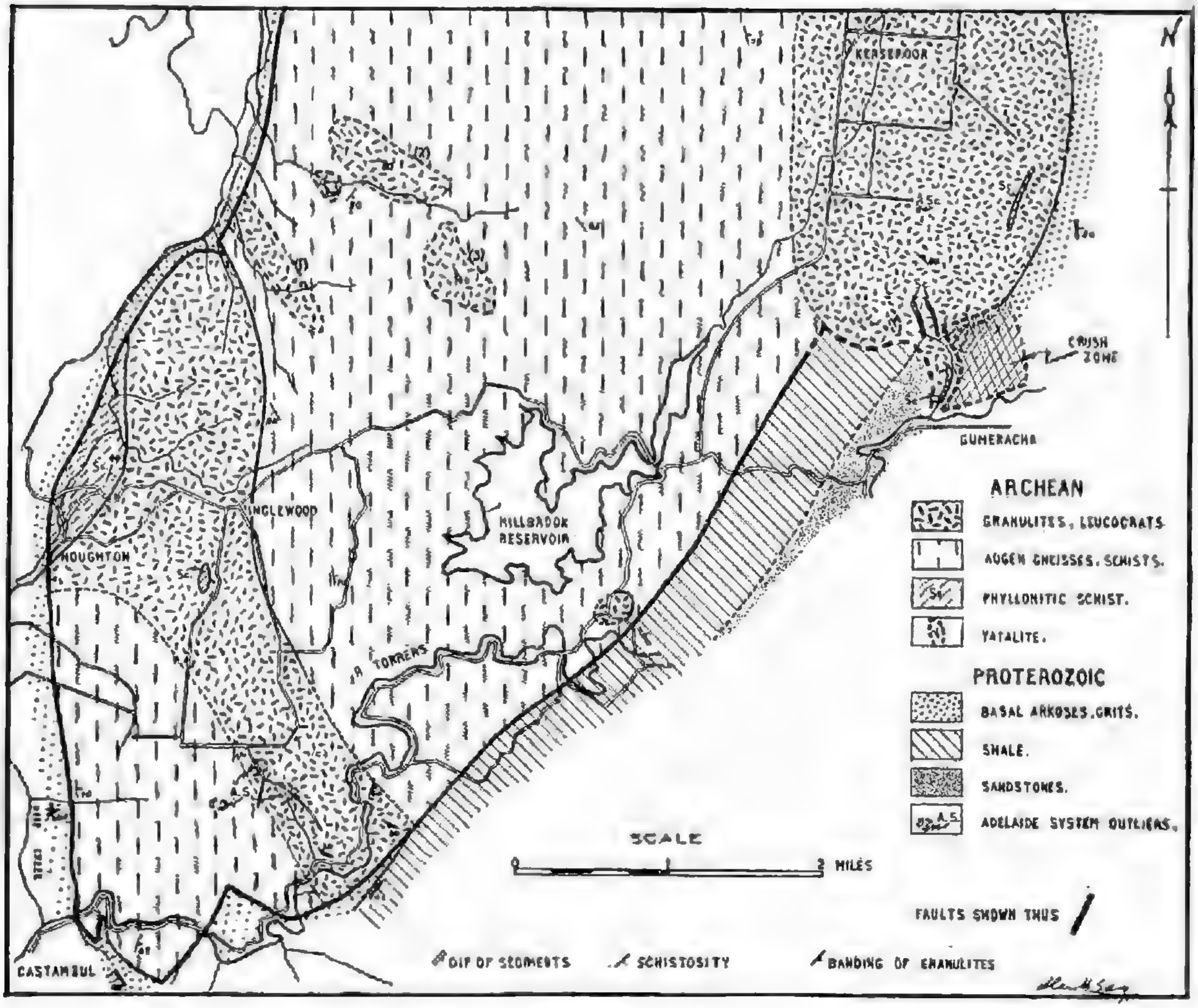

Fig. 4

Map showing some detail of the relations between granulites and gneisses.

occasional barytes veins. Outcrop (2) is rich in quartz and biotite, while micaceous haematite is abundant in places. There are additional small granulite masses which are not shown on the map, the largest being several miles north of Kersbrook.

A granulite from Kersbrook (8935) is typical of those rocks of dioritic composition and shows palimpsest cross bedding. It has alternate light-coloured moderately coarsely-crystalline bands, alternating with light-greyish fine-grained bands. The latter show the cross bedding outlined in actinolite and ilmenite grains (see Pl. VII, Fig. 3). The bands differ in that the fine part shows cross bedding and contains quartz, while the coarse parts lack quartz and have less epidote, diopside and actinolite. The most abundant mineral is plagioclase, andesine (Ab_{68}), while actinolite is well developed as closely-packed fibrous bands. Accessories are epidote, ilmenite and actinolite.

Another specimen, (8942), from Kersbrook has the composition of an adamellite. It is a light-brown medium-grained rock with elongated bluish opalescent quartz together with feldspar, biotite and a little epidote. The variability within these rocks is demonstrated by the fact that in two different microscope slides cut from the same specimen, one did not contain diopside and sphene, while the other had 4% of these two minerals. The composition of the plagioclase and the abundance of biotite also varied considerably. The rock has a granoblastic texture and consists of quartz, fresh microcline, cloudy plagioclase (andesine Ab_{68}), biotite and diopside with accessory apatite, sphene, ilmenite, leucoxene and zircon. The composition of this rock is compared with specimens previously analysed.

TABLE I

	"ADAMELLITE" Anal. Spry	"DIORITE" Anal. Alderman Mawson (1926)	"DIORITE" Anal. Benson Benson (1909)
SiO_2	69·25	58·19	56·85
Al_2O_3	13·40	15·28	14·76
Fe_2O_3	2·69	1·58	4·48
FeO	1·47	1·23	1·21
MgO	1·53	3·85	3·89
CaO	2·47	8·72	7·91
Na_2O	3·03	4·76	5·34
K_2O	4·66	3·02	1·91
H_2O+	0·49	0·16	0·12
H_2O-	0·16	0·29	0·08
P_2O_5	0·13	0·48	0·51
MnO	0·01	0·05	0·12
TiO_2	0·91	2·65	3·11
CO_2	—	—	—
Ba	Trace	—	—
S	Trace	—	—
Total	100·16	100·26	100·32
NORMS			
Quartz	26·88	2·16	2·54
Orthoclase	27·80	17·79	11·12
Albite	25·68	40·35	45·06
Anorthite	8·90	11·40	10·84
Diopside	2·16	18·38	14·69
Enstatite	2·80	1·00	—
Hypersthene	—	—	2·80
Ilmenite	1·67	2·74	2·89
Haematite	1·28	1·60	4·48
Apatite	0·34	1·34	1·34
Titanite	—	2·94	3·92
Magnetite	2·09	—	—

Another rock from the Torrens Gorge is an acid biotite granulite with the composition of an adamellite, No. 8923. It has the appearance of a light-coloured gneissic granite with bluish opalescent quartz and black biotite. It consists chiefly of a coarsely-perthitic microcline with slightly less quartz drawn out in elongated forms. Biotite is irregularly crystallized and does not show a directed texture in the thin section. A little highly-altered oligoclase is present. Accessories are rutile with much leucoxene and zircon. Although the amount of plagioclase at first visible is low, close inspection shows that a considerable amount is bound up with the microcline in the coarse perthite. The rock would thus be classified as an adamellite rather than a granite.

A typical specimen from Houghton is (8937). It is a light grey rock with a fine even grain and has regular bands 1-2 cms. wide traversing it. It consists of moderately large interlocking irregularly-shaped crystals of cloudy plagioclase with subordinate microcline, diopside and epidote. The plagioclase often shows effects which are probably due to straining. These are:

(1) bent and warped twin lamellae,
(2) irregular secondary twinning,
(3) undulose extinction,
(4) peripheral cracking and granulation.

The feldspar is highly altered and the composition could not be determined by complete orientation procedure on the Universal Stage, and extinction angles were measured from 010 in the symmetrical zone. This method, however, gave several anomalies. It was found that even in the zone normal to 010, albite twins did not extinguish symmetrically. This may be due to the warping of the twin plane which has already been mentioned, or may be due to differences in composition of adjacent plagioclase twins. Emmons (1935) has noticed that "a very disturbing occurrence of such variations is in adjacent twins which may differ optically in composition by more than 10%." In these rocks there is an indication of differences of 5% and this is also suggested by the fact that the degree of alteration of adjacent twin lamellae often differs also.

This specimen shows the coarse antiperthite which is a common feature of the granulites. Crystals of microcline are enclosed by a larger crystal of plagioclase with the individual inclusions in optical continuity with each other and in some cases with the host also (see Pl. VIII, Fig. 3). In one instance where both the host and inclusion are twinned, the similar optical continuity is readily seen. The 010 direction of the albite twin-plane coincides while the twin-planes of the pericline twinning in the plagioclase and the microcline twinning in the potash feldspar are at 54°, indicating coincidence of the 001 direction in both crystals. This antiperthite is considered to have been formed by the replacement of microcline by plagioclase and implies an addition of soda after potash to the granulites.

The pyroxene which is present in most granulites and which is abundant in this rock is a pale green diopside. Occurrence of the fresh unaltered mineral is uncommon, and usually the pyroxene is rimmed or entirely replaced by a pale green fibrous uralitic actinolite. The diopside indicates the high grade reached by the rocks and also suggests that the original sediments were rich in lime and magnesia.

Epidote occurs both as the pleochroic yellow variety in large crystals, and as tiny colourless granules formed by saussuritization of the plagioclase.

Apatite is an accessory and is brown and pleochroic with an optic axial angle of 40°. Epidote is frequently associated intimately with it. Black opaque grains of ilmenite have pale green actinolite growing around them.

Rock (8936) from Houghton is closely similar to the generalized description above and is notable because of abundant tiny colourless to pink or blue euhedral prisms of tourmaline included in the plagioclase. Many of the granulites show this feature.

There is a variety of granulite which outcrops south of the Houghton cemetery and which has been described as an "ophitic diorite". In the hand specimen of a moderate fine-grained rock a poikiloblastic texture is visible where the plagioclase includes granules of diopside. The granulite is a greenish rock with a very fine banding due chiefly to diopside grains. It consists chiefly of oligoclase-andesine (Ab_{70}) with diopside and microcline and lesser amounts of sphene, epidote and apatite and a little quartz. The extreme variability in composition is shown by modes of three slides cut from the same hand specimen. An analysis by Alderman is given in Table I. This specimen was previously called a monzonite by Mawson (1926).

Slide 1218	No. 1	No. 2	No. 3
Diopside	15	30	20
Plagioclase	60	35	40
Microcline	10	18	23
Sphene	8	9	7
Quartz and accessories	7	8	10

The poikiloblastic texture is shown by large crystals of plagioclase with rounded inclusions chiefly of diopside but also of microcline and quartz. The microcline has the previously mentioned antiperthitic relation with the plagioclase, while the quartz occurs as groups of very tiny granules. The poikiloblastic texture is similar to the coarse antiperthite and is probably due to a similar replacement process. It is considered that there was a fine-grained aggregate of microcline and diopside originally and that soda-rich introductions produced a plagioclase by replacement of the microcline while the diopside remained unaltered. The plagioclase developed into large crystals and enveloped diopside over considerable areas.

Retrograde metamorphism has not affected the granulites to the same extent as the gneisses, but mineralogical breakdowns have produced schistose granulites and phyllonites as lenses and bands within the granulites. The complete breakdown of the crystalline rocks to finely schistose bands of phyllitic appearance is possibly due to shearing along preferred directions.

Rock (8929) is a schistose granulite from Houghton. It is a dark grey medium-grained crystalline rock with a distinct banding and a fissility imparted parallel to this direction by micas. The change from the granoblastic texture typical of the granulites to the schistose texture of the phyllonites is shown by the slide which has been cut so as to reveal adjacent bands. There are alternate zones of granulose microcline perthite and quartz with fine-grained schistose sericite-chlorite bands. The quartz has undulose extinction while the microcline shows fracture and peripheral sericitization. In the schistose parts skeletal crystals of plagioclase showing twinning remain as vague residuals after practically complete replacement by sericite. There is a considerable amount of white mica in cracks and enclosures within the quartz and feldspar as though potash had entered along cracks and partially replaced the minerals. Biotite is moderately well crystallized and there is accessory apatite, leucoxene, zircon and ilmenite.

The schists often resemble those derived from the augen gneisses and rock (8932) is a dark green schist found cutting the granulite in the Torrens Gorge. It shows a well-directed highly schistose texture with small porphyroblasts of quartz, untwinned albite, rutile, ilmenite and apatite set in a matrix of green biotite and chlorite with accessory leucoxene and micaceous haematite. The

longer growths of green biotite and pale green chlorite are frequently set at an angle to the schistosity.

Rock (8930) is a pale green highly fissile rock found cutting the granulites at Inglewood. It is a fine-grained schistose rock with a foliation due to strings of quartz porphyroblasts parallel to the schistosity which is produced by the common orientation of small laths of sericite and chlorite. Quartz is plentiful as clear, colourless crystals with broken and irregular shapes. Calcite is also present as idioblastic crystals, pale brown and pleochroic, each crystal being intimately associated with or surrounded by a dark, semi-opaque skeleton of rutile and haematite. Tourmaline is an abundant accessory as pleochroic brown prisms and hexagon sections, with the latter frequently showing a colour zoning with a pale centre. Pyrites is also a common accessory.

LEUCOCRATIC GRANULITES

The leucocrats are white granulites consisting of quartz and feldspar and lacking the melanocratic minerals diopside, actinolite, hornblende, epidote and biotite which are typical of the normal granulites. They are less common than the grey and green varieties and occur in smaller masses. Outcrops may cover a few square feet or over an acre in area. The chief occurrences are just south of the Houghton School and at outcrop (3) on the map, while lesser masses occur south-east of Kersbrook and south of the Torrens Gorge. They vary considerably in grain size and texture, some being almost pegmatitic in appearance and others looking like recrystallized arkoses. The granulitic banding is less prominent and the most notable directed texture is due to extremely elongated grains of quartz. These are the rocks which Benson has referred to as "gneissic aplites", and they are considered to be feldspathized sandstones.

Rock (8924) from the locality (3) mentioned above is very rich in glassy quartz with only a little feldspar. It is well banded and appears to be a recrystallized quartzite with only minor feldspathization.

Rock (8940) from the quarry south of the Houghton school is a pure white rock similar in appearance to a quartzite. It consists of quartz, andesine and microcline with accessory muscovite and sphene. The quartz is extremely elongated and is up to 15 mm. long and 1 mm. in diameter, thus giving a pronounced lineation to the rock. The plagioclase and microcline show the coarse antiperthitic relationship.

Rock (8939) was taken nearer the Houghton school and differs in that the quartz is not elongated, but is concentrated in bands of granules in a white feldspar-rich rock. The texture is granoblastic and the quartz is mainly in bands between the main mass of albite (Ab_{87}) and microcline, which again are sometimes antiperthitic. There is accessory rutile, muscovite and tiny euhedral tourmaline crystals. A little crushing and sericitization has taken place.

Rock (8927) is from Kersbrook and is a white fine-grained feldspar rock with the appearance of a quartzite. A little micaceous haematite is crusted in joints. The rock consists almost entirely of irregularly shaped interlocking oligoclase-andesine (Ab_{70}) crystals, with minor amounts of antiperthitic microcline, biotite, chlorite, sericite, ilmenite and tiny euhedral tourmalines. Quartz is entirely lacking.

The leucocrats appear to have originated under similar conditions to the normal granulites and differ primarily because of their original sedimentary condition. They contain relatively less lime, iron and magnesia and are considered to be due to the feldspathization of a pure arenaceous rock.

Like all the high-grade rocks, the leucocrats have been retrograded to some extent, and phyllonitic schists have been derived from them. North of the

Houghton school the leucocrat becomes increasingly altered until there is an area of phyllonite which extends for over a mile to the north. Rock (8926) is an example of this schist. It is a pale grey compact fine-grained rock with scales of mica adhering to joint faces. Although consisting almost entirely of sericite it is not particularly schistose in the hand specimen, and in the field it retains much of the appearance of the parent granulite. In addition to the finely micaceous sericite, chlorite and quartz are also present with accessory ilmenite, rutile, tourmaline and zircon. The rock is due to the complete breakdown of a feldspar-quartz leucocrat. Benson (1909) noticed this rock and called it an "altered diorite".

While the augen gneisses are generally accepted as having a sedimentary origin, the granulites are more open to question and evidence is presented to indicate that they also are derived from sediments rather than being due to metamorphism of an igneous rock.

(1) The complete heterogeneity and variability of composition, both mineralogical and chemical, points to an addition of material to an originally variable sediment by metasomatism. If the rocks were igneous then this variability must be due either to original differences in a complex intrusion or to extreme metamorphic differentiation, and is not substantiated by further evidence.

(2) The strongly-developed banding is considered to be due to mimetic crystallization after sedimentary bedding. If the rocks were intrusive then again a complex process of igneous or metamorphic differentiation must be postulated. This banding may be mapped in the field and is folded into structures identical with those of sediments.

(3) The frequent occurrence of textures which closely resemble sedimentary cross-bedding outlined in grains of diopside, actinolite or ilmenite are difficult to explain on an igneous basis.

(4) There are no intrusive contacts between the granulites and the gneisses and their lack of cross cutting or discordant margins does not support a process of intrusion.

(5) The granulites merge into the augen gneisses across the strike through a zone of transition gneisses which are intermediate in properties between the two types.

(6) There is present a quartz-rich leucocrat which closely resembles a re-crystallized arkose in its chemical, mineralogical, textural and field properties. This rocks is an example of an arrested stage in the feldspathization process which finally produces rocks consisting entirely of plagioclase.

The granulites are considered to have been formed by a process of granitization which preferentially altered certain selected horizons in a system of sediments. The rocks were probably sandstones and semi-pelites, possibly greywackes which reached a high grade of regional metamorphism and suffered alkaline additions (potash first and soda later), together with minor amounts of boron and phosphorus. There was probably a partial, irregular desilication process. As the original sediments are not present and retrograde metamorphism has altered the rocks since, the mechanism of this early process is in doubt. However, it is considered to have been a gentle replacement, molecule by molecule at approximately constant volume, so that original structures were not distorted. The rocks were high-grade gneisses rich in plagioclase and diopside and were folded while still in the migmatitic state. Later retrograde changes due to sericitization, saussuritization and uralitization did not usually affect them as much as the gneisses. Secondary actinolite, epidote and albite with sericite, chlorite and biotite are the main retrograde products.

The nomenclature of these hybrid rocks is difficult. The original term "Houghton diorite" is misleading, in that it infers both a constancy of composition and an igneous origin. The term granulite is used here to imply a metamorphosed sediment, of high grade, rich in feldspar, with quartz (when present) typically elongated.

In general the granulites are rich in oligoclase and are poor in quartz. The application of the anorthite content of the plagioclase as an indication of the metamorphic grade or facies was not attempted, as the lack of equilibrium between the minerals in the rocks is everywhere evident. It is a striking fact that the granulites, which are chiefly composed of feldspar and which consequently appear free from any directed texture (apart from the foliation) show a high degree of preferred orientation in the optical directions of the feldspars even with a brief petrofabric analysis.

Transition gneisses

A group of banded schists and gneisses is exposed in the Torrens Gorge in the zone between the granulites and augen gneisses. The amount present is small, there being a width of about 100 yards to the west and perhaps half-a-mile to the east of the granulites, but the rocks could not be found further to the north. The rocks combine some of the characteristics of both the granulites and augen gneisses and show the gradual change from one type to the other. The transition gneisses may be rich in quartz and have feldspar augen, being similar to the augen gneisses, but may contain hornblende and epidote which are typical of the granulites.

No. 8934 from the Torrens Gorge is a typical specimen. It is a dark green gneiss with small augen of feldspar set in a fine schistose matrix of hornblende. Microscopically the rock consists of bands rich in hornblende or plagioclase and these are the only constituents of any importance. The plagioclase is andesine (Ab_{68}) and is extremely altered. The amphibole is a fresh bright green-brown hornblende and while occasional crystals occur in the granulites, none was found in the true augen gneisses. A colourless tremolite is invariably associated with this hornblende and grows around the green crystals in perfect optical continuity. The two minerals have the same extinction angle from common cleavages and have similar optical properties. The junction between the coloured and colourless amphibole is sharp. Accessories in this rock are epidote, calcite, sericite, ilmenite and zircon.

There are frequent bands of fine-grained schists cutting the gneisses. There are compact, dark green rocks with poorly developed augen and directed texture. No. 8925 is a fine-grained aggregate of ragged crystals of hornblende with tremolite together with extremely altered plagioclase, biotite, epidote, apatite, ilmenite, calcite and quartz.

A specimen, No. 8941, occurs as narrow bands cutting the granulite in the bed of the Little Para River north-east of Houghton. It is a soft green schist composed chiefly of amphibole and is cut by white bands of calcite. It is strongly schistose with the cleavage set at a high angle to the compositional banding shown by calcite. The minerals are fresh and well crystallized and the rock consists chiefly of amphiboles, micas, calcite and quartz with accessory apatite, epidote, leucoxene, ilmenite and micaceous haematite. There are ragged green biotite crystals and pale-green penninite present. Ilmenite is seen to be breaking down to leucoxene and micaceous haematite.

Evidence suggests that the original sedimentary composition was between that of the gneisses and the granulites and that they shared additions of soda with the latter. The effects of retrograde metamorphism are difficult to determine in this group as primary and secondary minerals are usually indistinguishable.

Fig. 1
Contortions in the Archean gneiss at Castambul.

Fig. 2
Granulitic banding near Houghton.
The rock face is about ten feet across.

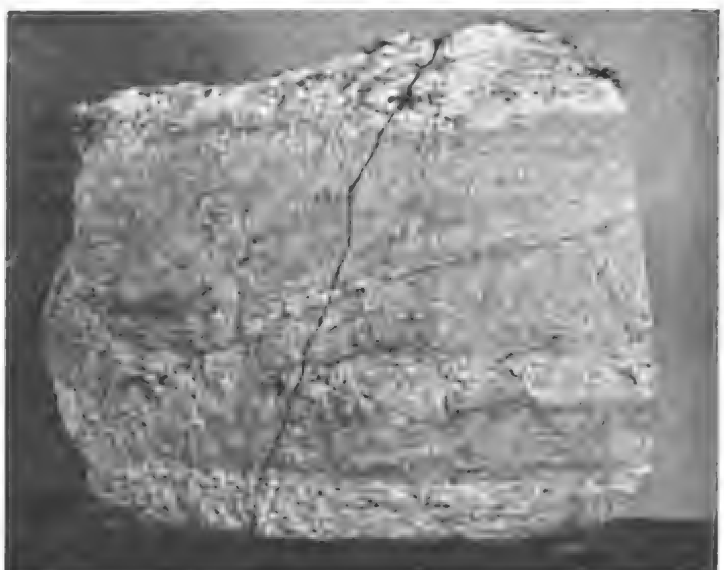

Fig. 3
A "dioritic" granulite from Kersbrook showing apparent cross bedding. The specimen is four inches long.

Fig. 4
Contortions in the Archean gneiss in the Torrens Gorge.

Fig. 2. Sericitization of feldspar. Magnification 35 x.

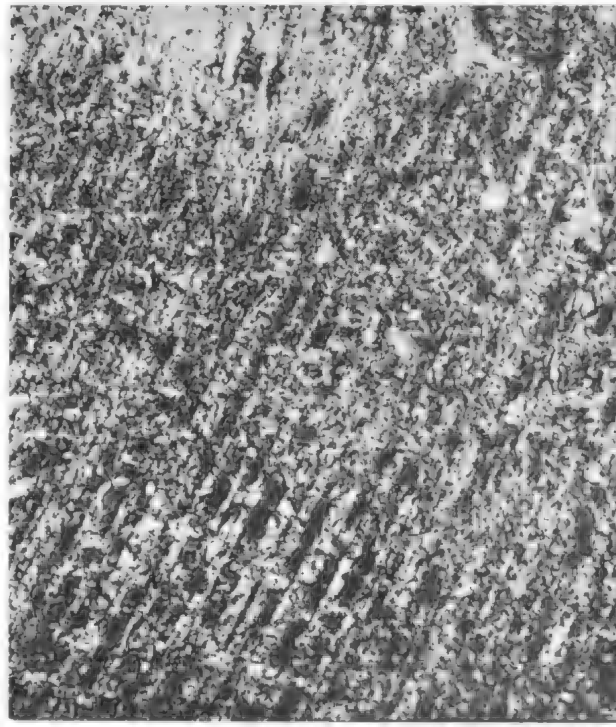

Fig. 4. Sericitization of plagioclase. Crossed nicols. Magnification 40 x.

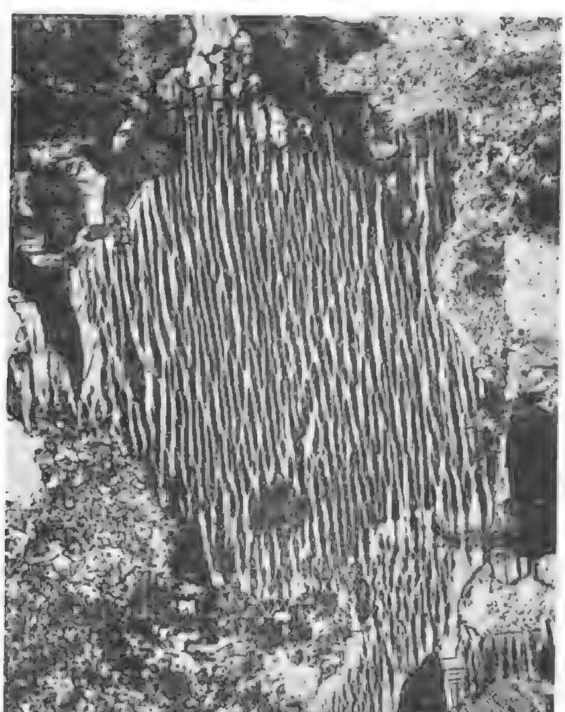

Fig. 1. Coarse microcline - albite - perthite. Crossed nicols. Magnification 85 x.

Fig. 3. Coarse replacement antiperthite. Crossed nicols. Magnification 25 x.

Pegmatites and Pegmatoid Rocks

Apart from the simple quartz-microcline pegmatites which are extremely common in the area, there are also a variety of rocks which have some of the characteristics of the pegmatites and may be related to them. There are complex plagioclase rocks which approach the leucocrats in appearance, but most difficult to explain is the rock which Benson (1909) termed "yatalite". He described it as "a coarse-grained pegmatite, composed of uralitic actinolite (after diopside), albite containing microcline, titaniferous magnetite, sphene and quartz." It occurs in narrow bands and veins near Houghton but is most notable in a very large outcrop which is shown on the map south-east of Kersbrook. Here it occurs as a lenticular mass several hundred yards long, surrounded by the normal plagioclase granulite, and consists of extremely coarsely-crystalline actinolite and ilmenite. The amphibole occurs in dark-green masses several feet across. If this was intruded as a large pegmatitic body, it would suggest that the diopside and ilmenite in the granulites had been introduced into the sediments, and so the yatalite is considered to be a segregation of excess basic minerals displaced by the process of granitization.

Unclassified types

There are a few minor outcrops of rocks of little importance but of passing interest in the area. These include the haematite schists of Inglewood and Castambul, the haematite quartzite north of Houghton, and the quartz tourmaline schist of the Humbug Scrub.

DISCUSSION OF THE MAPS

This paper is concerned with Precambrian rocks, and the Tertiary gravels and Recent alluvial deposits are not shown on the maps. It is not possible to show certain lithological boundaries accurately due to cover by later deposits. The contact between Archean schists and Proterozoic sheared arkose is in many places difficult to recognise because of the similar appearance of the two rocks. The boundary between the granulites and augen gneisses may be quite sharp in one locality while there may be a zone of transition gneisses and schistose granulites which make the limits of each type indefinite in another place. The boundaries between these two rocks in the Torrens Gorge may only be placed approximately for this reason.

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SOME NEW AND LITTLE-KNOWN SHORE-BUGS (HETEROPTERA-SALDIDAE) FROM THE AUSTRALIAN REGION

BY G. D. RIMES

Summary

This paper describes four new species of Saldidae – Pentacora leucographa, Saldula coorongensis, S. brevicornis and S. psammobia – which inhabit the shores of salt-water lakes and estuaries, or the banks of sandy creeks, in South Australia. Descriptions are given of the eggs and five immature instars of each new species.

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[Read 9 Nov. 1950]

SUMMARY

This paper describes four new species of Saldidae—*Pentacora leucographa, Saldula coorongensis, S. brevicornis* and *S. psammobia*—which inhabit the shores of salt-water lakes and estuaries, or the banks of sandy creeks, in South Australia. Descriptions are given of the eggs and five immature instars of each new species.

In the laboratory all species were successfully reared in air-tight containers, the bottom of which were covered with damp blotting paper. They fed readily on dead *Drosophila* adults. Eggs were laid under the surface of the blotting paper and the young were removed as they hatched. This was necessary to prevent them preying on unhatched eggs. All instars of all species are predaceous. The processes of mating and copulation are described. In the field the eggs of *P. leucographa* and *S. psammobia* are laid into the stems of samphire plants and this probably applies to *S. coorongensis* also but has not been observed.

The characteristics of all known Australian genera are described, together with a key for their identification.

INTRODUCTION

Only four species of Saldidae have been previously recorded from the Australian region: *Acanthia reuteriella* Kirkaldy 1899 and *Acanthia cygni* Kirkaldy 1899, both fresh-water forms from Western Australia; *Acanthia salina* Bergroth 1893, from salt-water pools, Admiralty Gulf, N.W. Australia; and *Salda nicholsoni* Hale 1920, from Wentworth Falls, New South Wales. This present work has added three new species of *Saldula,* and one new species of *Pentacora.* Observations of their ecology and biology have been made, including the description of a complete life cycle.

The author wishes to acknowledge his indebtedness to Mr. D. C. Swan, Entomologist, Waite Agricultural Research Institute, and Messrs. H. Womersley and G. F. Gross of the South Australian Museum, for advice and guidance during the preparation of this work. All new material described herein is lodged in the South Australian Museum.

Key to the Australian Genera

1. Membrane with five areoles - - - - - Pentacora Reuter
   Membrane with four areoles - - - - - - - - 2
2. Membrane with base of inner areole extending more than two-fifths of its length beyond base of second areole - - - - - Salda Fabricius
   Membrane with base of inner areole extending less than two-fifths of its length beyond base of second areole - - - - Saldula Van Duzee

Pentacora Reuter 1912

Pentacora Reuter, 1912, Of Finska Vet. Soc. Forh., LIV, Afd. A., No. 12, pp. 7-10, Orthotype *P. signoreti* Guer.

Body oblong. Eyes converging slightly towards the front. Ocelli slightly distant or nearly touching. Rostrum reaching middle coxae. Second segment of

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antenna equal in length to width of head or distinctly longer. Pronotum narrowing moderately towards front, base wide, sides explanate, lateral margins rounded strongly towards tip or forming distinct angles. Callus not attaining lateral margins; a transverse impression behind middle of callus. Scutellum wider than long, bearing a transverse impression. Hemielytra distinctly punctate, often densely so and for the greater part bearing bristles. On corium the interior vein bifurcates towards tip, the branches reaching suture of the membrane. Membrane with five complete oblong areoles, the first or inner produced slightly beyond the base of second, its tip not attaining tip of second. Last sternite in female reduced, not covering genitalia. Hind tarsal segments unequal, the third somewhat shorter than second. Genotype:—*Acanthia signoreti* Guer.

Acanthia salina Bergroth 1893, should rightly be placed in this genus, on Bergroth's description of the membrane ("membrana cellulis quinque completis instructa"). The two Australian species may be separated as follows:

1st and 4th antennal segments equal in length - - - - *P. salina* Berg., 1893
1st and 4th antennal segments unequal in length, i.e., 4th antennal segment two-thirds longer than 1st - - - - - - - - **P. leucographa** sp. nov.

Pentacora salina Berg., 1893

Acanthia salina Bergroth, 1893. Ent. Mon. Mag., **29**, 279.

Salda salina Hale, 1924. Proc. Linn. Soc. N.S.W., **49**, (4), 466.

Oval, dark-coloured, covered above with very dark hair, head, pronotum and scutellum shining. Hemielytra opaque. Spot on sides of pronotum narrowly continuing forward and behind to following margin. Posterior lateral edges of scutellum forming a V-shaped sign apically with the hind band of clavus. There is a median spot and a spot near the internal angles of the corium. Edges of acetabulum and posterior edges of metasternum and apical margins of ventral segments, legs and often frons slightly golden. Femora, except tip, and tip of tarsi black. Head (with eyes) distinctly wider than apex of pronotum, pronotum long medially. Frons with oblique black impressed line on each side. Antennae similar in colour, and in adult, first segment diametrically opposed seen unequally from above and provided with spurs unequally protruding; second two and one half times longer than first; third half as long again as first; fourth one-third part shorter than third. Pronotum and scutellum like soft leather, edges raised. Hemielytra not projecting beyond tip of abdomen. Corium and clavus clearly punctulate. Membrane with five complete cells which are dark and smoky with dark veins. Hind tibia and tarsus dark and spinous.

Pentacora leucographa sp. nov.

Holotype Male—Eyes prominent. Head, including eyes, distinctly wider than anterior of pronotum, slightly brownish, with inner edges of the eyes devoid of facets. Deep cleft between ocelli and eyes, gradually diverging from level of ocelli and meeting eyes half-way along their inner margins. Between eyes and this cleft is a raised light-coloured patch. At the posterior tip of this raised patch is a long bristle. Frons bearing a pair of bristles at its anterior edge and another pair half-way between these and the ocelli. Ocelli slightly raised, almost contiguous, dark orange. A pair of large bristles one-third of the distance from the ocelli to the neck and separated by a distance equal to the width of the ocelli. Rostrum dark-brownish, shining and extending beyond middle of hind coxae. Antenna with first and second segments whitish, with short black bristles. Third and fourth segments dark brown with short pubescence and a few long bristles. Total length of antenna 2·51 mm. Ratio of segments I: II: III: IV: 15:35:25:25. Ratio antenna to body length is 71:100.

Pronotum shining black with silver pubescence, lateral edges straight with large white patches extending nearly their entire length. Strongly convex callus extending two-thirds of length of pronotum. Fovea placed well in front of middle of callus; also two very slight depressions on each side about one-third of the distance from central fovea to lateral edge of callus. Scutellum shining black with short golden pubescence and very marked contours (fig. 1), the posterior half with transverse striations. Scutellum and pronotum with a few long bristles.

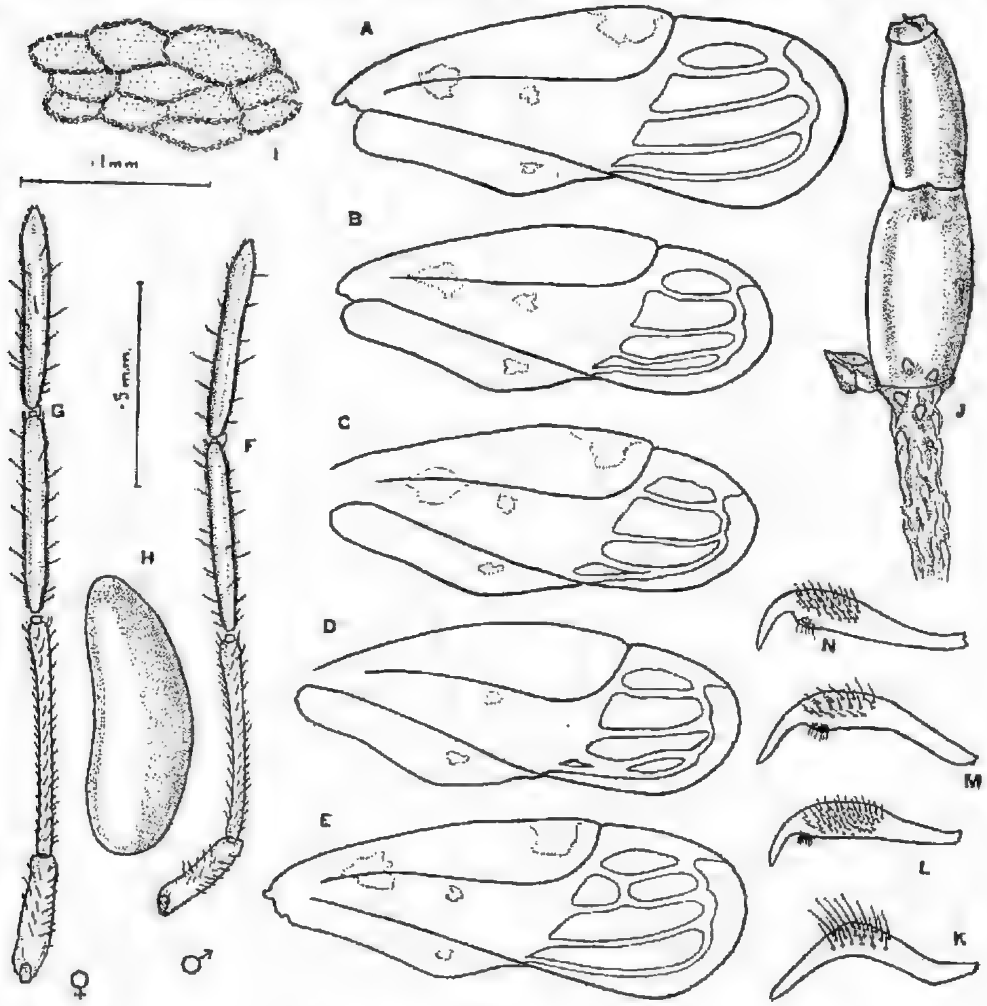


Fig. 1

Saldula psammobia—A. to E, variation in membrane venation; F, Male antenna; G, Female antenna; H, Egg; I, Surface of egg; J, Stem of samphire (*Salicornia* sp.) with eggs inserted; K - N, Parameres. K, *Pentacora leucographa;* L, *Saldula coorongensis;* M, *Saldula psammobia;* N, *Saldula brevicornis.*

Clavus dull black with sparse, short, black pubescence and a few black bristles. A long white patch extending centrally in clavus for the posterior third of its length. Corium dull black with very spare short black pubescence and a few black bristles. A large white patch mid-way on outer edge of corium; also one at anterior and extending back along the inner edge narrowly for a greater or lesser extent. Corium with one median longitudinal vein bifurcating at its distal end, and a cross vein extending from point of bifurcation to embolium.

Embolium for the greater part shining black; posterior third dull black with sparse black pubescence. A whitish transparent patch opposite anterior white patch of corium. Also an opaque white patch at posterior end, extending the whole width of embolium. Membrane usually opaque and shining, but may be dull, brownish. Veins black and distinct with a few short black hairs. Outer edge of membrane dull black, with short black pubescence extending as far as tip of fifth areole.

Ventral surface shining black with short silvery pubescence. Prosternal area: propleura mostly white, portion of xyphus surrounding coxae white. Mesosternal area: sternal area surrounding coxae of mid-leg white, posterior edge of epimeron white. Metasternal area: posterior edge of metasternum white, sub-coxal flange white. Abdominal sternites shining black with short silvery pubescence, posterior edges whitish. Proximal end of coxae whitish, distal end brown. Tibiae whitish, inner surface with dark band running its whole length. Distal tip of tibiae dark brown. Second and third tarsal segments in hind leg differing in length, third being one-sixth shorter than second; first and third blackish, second white. Combined length of the hind femur, tibia and tarsus equal to body length, with proportions respectively of 31:50:19. Male length 3·50 mm.; width 1·4 mm. Female slightly larger than male: length 3·90 mm.; width 1·7 mm. Last abdominal segment truncate (typical of genus, see fig. 1). Antennal proportions different from male. Of a total length of 2·86 mm. the proportions of the segments are I:II:III:IV:14:42:22:22.

Type locality—Port Adelaide River Basin, South Australia.

The fourth and fifth vein in some variants of *P. leucographa* may closely approximate or actually coalesce for a greater or lesser part of their length. One variant (see fig. 2 e) has the veins fused completely for their proximal half, so that the fourth areole is much shorter than the third and fifth which are contiguous for a greater or lesser distance basally. This is of interest as it is the typical wing venation of a separate genus, *Chiloxanthus* Reuter.

The genus *Pentacora* has previously only been recorded from North America. The discovery of this Australian species shows that the genus may be much more widely distributed than has hitherto been suspected.

Salda Fab., 1803

Salda Fabricius 1803. Syst. Rhync. 113. Orthotype *S. littoralis* (Linn.) (= *S. zosterae* (Fab.).

To the references cited by Van Duzee 1917 may be added Saunders 1892, Distant 1904.

Body broadly oval or oblong oval in macropterous forms. Head deflexed, narrowing slightly towards front. Ocelli together. Rostrum reaching middle of hind coxae or a little beyond. Antennae slender, with short pubescence and a few long bristles. Second segment from two and a half to three times as long as first. Pronotum narrowing strongly towards front, apical margin slightly narrower than head; sides straight or rounded. Callus large, extending to three-fourths of width of pronotum. Base of pronotum widely emarginate. Scutellum wider than long, base plainly visible and always a transverse impression from the base. Hemielytra variably punctulate, always without silky black patches. Corium with veins joining, sometimes very slender or absent, interior vein bifurcating at its distal end, the bifurcations reaching the membrane. Embolium totally black. Membrane showing four complete areoles, base of the first or inner areole extending two-fifths or one-half beyond base of second, the apex also in the macrapterous forms placed above the apex in this way. Apex of second

areole not extending further than apex of third. Membrane often abbreviated. Wings for the greater part abbreviated or absent. Hind tarsal segments unequal in length. Last ventral segment in the female roundly produced. Genotype—*Acanthia littoralis* Linnaeus.

Salda nicholsoni Hale, 1924

Salda nicholsoni Hale, 1924. Proc. Linn. Soc. N.S.W., **49**, 465, pl. xlviii, fig. 4 a-d.

S. nicholsoni is the only authentic species of this genus yet recorded from Australia, being a fresh-water form collected from the base of a waterfall at Wentworth Falls, New South Wales.

Both *Acanthia reuteriella* Kirk. and *Acanthia cygni* Kirk. have been referred to as species of *Salda* by Hale (1924). As their descriptions give no clue to their generic identity, these species must be re-examined before designation to a genus. Both are fresh-water forms from Western Australia. Kirkaldy in his description of *A. reuteriella* says, "Posterior tibiae nearly three times as long as tarsi, first tarsal segment one-fifth longer than the second, which is twice as long as the large falciform claws." Apparently Kirkaldy has mistaken the numbers of tarsal segments, three being present in all Saldidae, the first being very short compared with the second and third which are nearly equal.

Saldula Van Duzee, 1914

Saldula Van Duzee, 1914 a, San Diego Nat. Hist. Soc., 2, 32; 1914 b, Can. Ent., **46**, 387.

Acantha Reuter 1895, Acta Soc. Sci. Finn., **21**, (2), 5-9. Reuter 1912, Ofv. Finska Vet. Soc. Forh., liv., **14**, (7), 71-72; idem (12), 8, 14.

Body oblong-oval, brachypterous forms obovate. Head subvertical. Ocelli almost contiguous. Rostrum attaining middle of intermediate or hind coxae. Antennae slender. Base of pronotum emarginate, sides straight or rounded. Callus not reaching lateral margins, but extending behind middle of pronotum. Scutellum wider than long, and bearing transverse impression. Hemielytra often with silky black spots. Corium with interior vein bifurcating towards tip, the branches reaching margin of membrane. Membrane showing areoles, spread out or abbreviated to a greater or lesser extent; if abbreviated, it nevertheless reaches tip of abdomen. Base of first or inner areole extending above base of second but not further than one-third its length. Apex of first areole reaching or nearly reaching apex of second. Third tarsal segment of hind leg shorter or longer than second. Last ventral segmen of female roundly produced. Genotype—*Acanthia saltatoria* Linn.

This is by far the largest genus in the family, and specimens of two other species besides those listed below have come to my notice, one from Launceston, Tasmania; and one from Vivonne Bay, Kangaroo Island, South Australia.

Key to New Species

1. Combined length of femur, tibia, and tarsus, shorter than body length — **S. coorongensis** sp. nov.
   Combined length of femur, tibia, and tarsus equal to body length - - - 2
2. Second antennal segment one-third longer than the third - **S. brevicornis** sp. nov.
   Second antennal segment only slightly longer than the third - **S. psammobia** sp. nov.

Saldula coorongensis sp. nov. (fig. I, L)

Holotype Male—Head, pronotum and scutellum shining black, covered with short golden pubescence. Embolium for the greater part shining black with

golden pubescence. Corium and clavus dull black, not shining, having grey patches; also bearing golden and black pubescence. Membranes without pubescence.

Eyes prominent, slightly brownish, with the inner edges devoid of facets. At junction of eyes with notocephalon a slightly raised, circular, light brownish area bearing a long brsitle, approximately ten times length of body pubescence. This area is the same size as the ocelli but not quite as spherical. Ocelli, almost contiguous, orange brownish, their approximating edges joining a raised portion of head. Frons bearing two pairs of long bristles, one pair near anterior margin, second pair half-way between these and ocelli. Two deep clefts diverging from ocelli and passing forward to anterior edges of eyes. Region of head behind ocelli without pubescence and deeply pitted. Rostrum light brownish, reaching mid-coxae of hind legs. Third and fourth segments of antenna thickly pubescent, with a few bristles; total length 1·58 mm., the ratio of segments is: I:II:III: IV::18:31:25:26. Antennae reach to ·46 of distance from front of head to tip of hemielytra. Pronotum shining black, bearing short golden pubescence. Callus extending slightly behind middle of pronotum; with a distinct fovea slightly in front of centre and a very slight depression one each side about one-third of distance from fovea to lateral edges of callus. Lateral edges of pronotum rounded. Scutellum shining black with short golden pubescence with very marked contours. Posterior half bearing transverse striations. Clavus, dull black, sparsely pubescent, with a whitish grey spot at posterior inner end, just behind apex of scutellum. A cross vein joins junction of this bifurcation with margin of embolium. Inner areole of corium dull greyish, with both black and golden pubescence. Anterior outer areole bearing a whitish patch at one half of its length from anterior end, and one at its posterior end, but chiefly black with greyish patches, and with both black and golden pubescence. Posterior outer areole dull black with golden pubescence. Posterior central areole greyish. There may or may not be a whitish patch opposite to that of corium; also a whitish patch at hinder margin of embolium with membrane extending whole width of embolium, or divided into an inner crescentic patch and an irregular outer patch. Membranes opaque, with irregular blackish and whitish patches; veins black, bearing a few short black hairs; outer margin of membrane black with short black pubescence and a whitish patch at its mid-point. Ventral surface of body black and shining, with short golden pubescence, posterior edge of each sternite yellowish. Femur with a series of brown spots along its whole length. Hind tibia slightly curved and bearing heavy bristles. Second and third tarsal segments equal in length. Combined length of hind femur, tibia and tarsus ·85 of body length. Proportions of femur:tibia:tarsus 32:47:21.

Length 3·47 mm.; width 1·6 mm.

Allotype Female—Length 3·80 mm.; width 1·80 mm. Ovipositor prominent. Last ventral segment roundly produced. No sexual dimorphism in antennal measurements.

Type locality—McGrath's Flat, Coorong, South Australia.

Saldula psammobia sp. nov.

Holotype Male—As for *S. corrongensis* except for dimensions and body pubescence; the latter slightly longer and more sparse than in *S. coorongensis*. In a total length of 1·74 mm. proportions of antennal segments are I:II:III: IV::15:30:27·5:27·5. Antennae reaching ·59 of distance from front of head to tip of hemielytra. Combined length of hind femur, tibia and tarsus equal in length to body. Length of male—2·97 mm.; width 1·4 mm.

Allotype Female—Slightly larger than male. Length 3·38 mm.; width 1·7 mm. Ovipositor prominent. Last segment ventrally produced. Marked sexual dimorphism of antennae. Antenna length 1·90 mm. the ratio of I : II : III : IV : : 16 : 32 : 26 : 26. This sexual dimorphism is very striking, the second segment of the antennae in the male being only slightly longer than the third, while in the female it is one-fifth longer.

Type locality—Port Adelaide River Basin.

This species shows considerable variation in wing venation and also in length of body pubescence. A continuous series of variants can be taken showing gradation from the typical four-celled membrane to a much reduced three-celled stage. The reduction occurs by the coalescing of the first and second veins. The veins themselves may vary from a definite black type to a hazy indefinite form scarcely distinguishable from the membrane itself. A cross vein may rarely be found extending across the third areole dividing it into two complete cells. As can be seen from the accompanying figure, the variant with the reduced inner areole has a much smaller membrane, the venation of both membranes clearly showing when the insect is at rest, no overlapping occurring as in the normal individual. This is the brachypterous form which is figured in the text. Variation also occurs in the length of the body pubescence in general appearance from the normal individual.

Saldula brevicornis n. sp.

Holotype Male—Head, pronotum and scutellum as for *S. coorongensis*, but the surface of the scutellum and pronotum are slightly irregular, having numerous closely placed small depressions. Antennae with third and fourth segments much darker than second and with thick pubescence and few short bristles; first and second segments without this pubescence but with numerous bristles. Antenna length 1·47 mm.; ratio of segments I : II : III : IV : : 16 : 32 : 25·5 : 26·5. Antennae reach to ·46 of distance from front of head to tip of hemielytra. Clavus very dark brown, very slightly shining, and with short golden pubescence, whitish spot at posterior inner end just behind apex of scutellum. Corium with venation as in *S. coorongensis*. Similar in colour to clavus, with golden and black pubescence. Outer edge of corium with a white spot half-way from anterior edge to cross vein, also a smaller white spot just anterior to this cross vein. Posterior outer tip of corium with a light patch. Embolium similar in colour to corium, bearing golden and black pubescence. A whitish transparent patch opposite the anterior patch of corium extending the width of embolium and becoming, at the outer edge, one quarter the length of the embolium. Also a whitish patch at hinder margin of embolium, with membrane extending whole width of embolium, or more usually divided into a crescentic inner patch and an irregular outer patch. Membrane with four areoles, transparent. Veins black and definite, bearing a few short black hairs. Outer margin of membrane dark brownish with short black pubescence and a whitish patch at its mid-point. Ventral surface of abdomen black or dark brownish with short golden pubescence. Legs whitish and transparent except for last tarsal segment and distal end of tibia and junction of tibia and femur which are dark brown. Combined length of femur, tibia and tarsus equal in length to the body, of relative proportions 31 : 49 : 20. Second and third tarsal segments equal in length.

Length 3·22 mm., width 1·45 mm.

Allotype Female—Slightly larger. Length 3·45 mm., width 1·62 mm.

Type locality—Wilson, South Australia.

ECOLOGY

Pentacora leucographa

This species has been collected throughout the Port Adelaide River area and inhabits tidal areas bearing samphire, and salty marshes. The area north of Adelaide has been inspected as far as Port Wakefield and, although no specimens were collected, this was probably due to inexperience or seasonal fluctuations. These insects move in short, rapid jumps of as much as eighteen inches and are difficult to detect as they usually occur along with shore flies, which they resemble in size.

Saldula psammobia

This species is restricted to the same localities and habitats as *P. leucographa*. Although it is sympatric with the latter there is a marked difference in their seasonal variation, *P. leucographa* disappearing entirely during the winter months from March onwards, the eggs apparently being the overwintering stage, while *S. psammobia* occurs until August, although gradually falling off in numbers after March. It is highly probable that further collecting will show this species to be present along the shore of St. Vincent Gulf, north of Adelaide, as there are numerous suitable localities and no apparent ecological barriers.

Saldula brevicornis

This species has been collected from Mount Serle, Flinders Ranges, to Wilson, South Australia. It inhabits the borders of pools and streams. Specimens have also been collected at various points along the River Murray, at Adelaide, and throughout the southern Mount Lofty Ranges. As there is a suitable network of rivers extending throughout the northern parts of South Australia and also into the eastern States, the distribution of this species should ultimately be shown to be fairly extensive.

Saldula coorongensis

This species has been collected in the Coorong, South Australia, from Kingston (South-East) to Lake Alexandrina. It occurs along the water margins where samphire is growing but is in greatest numbers at the junction of the samphire areas with the grass-bearing soil margins, and apparently breeds throughout the whole year, all instars being readily collected in mid-winter.

The fact that the ranges of distribution of *S. psammobia* and *S. coorongensis* were allopatric by a distance of only 50 miles, necessitated experiments to determine if they would interbreed. No interbreeding was found to occur.

BIONOMICS AND DESCRIPTION OF IMMATURE STAGES

So far as is known, all members of the family are predaceous. *Saldula psammobia* appears to feed chiefly on shore flies. All instars feed on larvae near the surface of the sand and continually probe the sand with their rostra in search of food, readily feeding on younger instars and the disabled of their own kind. *Pentacora leucographa* and *Saldula coorongensis* exist on the same diet. The above three species together with *Saldula brevicornis* were successfully kept in the laboratory in air-tight containers, the bottoms of which were covered with moist blotting paper. The saldids had no hesitation in feeding on dead ferment flies of *Drosophila* sp., which were introduced daily. When reared in these containers, care must be taken to remove the young instars as soon as hatching occurs, as they feed readily on the eggs which are inserted just below the surface of the blotting paper.

Mating was observed in the laboratory and in the field, and in each case a definite courtship occurred before-hand. All four new species described in this paper behaved in a similar manner. The female remains motionless after the male approaches. They touch antennae, the male becomes agitated and mounts the female's back with a sudden spring, and thence moves to her side, copulation occurring while the two bugs are side by side. The male's right or left wing becomes displaced, and the genital apparatus of both bend towards each other. The genitalia are perfectly symmetrical, there being no particular preference for one side, the same pair repeatedly copulating from either side. The female may walk around during copulation, the male securely retaining his position, but definitely not by the use of his displaced tarsi or tibiae, although it is possible that the coxae or femora may have some action in this respect. The male must be rapid in his approach and retreat from the female, as she makes deliberate attempts to insert her rostrum into his body.

Eggs are normally inserted into the fleshy stems of samphire by *Saldula psammobia*, *Pentacora leucographa*, and also presumably by *S. coorongensis*, although no eggs of this species have as yet been obtained in the field; in the laboratory they prefer samphire to sand. These species, as well as *S. brevicornis*, when kept in the laboratory on moist blotting paper, inserted their eggs in the paper around the edges of the containers. The eggs of the three new *Saldula* species all have a finely ridged surface, probably due to the impressions caused by the follicular cells of the ovarioles during maturation. Any accurate comparison of the eggs is not practicable, all varying within the same limits, the average size being 0·7 mm. long and 0·25 mm. wide. The eggs are whitish, the anterior being slightly pointed, the posterior pole somewhat wrinkled. Eggs were obtained from *Saldula psammobia* by two methods. The first was in containers with a layer of sand on the bottom of samphire placed therein. The second was with damp blotting paper. Those eggs inserted in the plant tissue had their posterior poles, which were usually wrinkled, protruding, whereas those in the blotting paper were devoid of such an area. Eggs were also dissected from the oviducts of *S. psammobia* and these were without any trace of the so-called micropyle region. This clearly suggests that doubt must be placed on Brindley's interpretation (Brindley 1934) of this area, which she describes in the egg of *Salda littoralis* as being ill-defined and occurring on the posterior pole of the egg which is left protruding from the surface of the mud in which it is laid. A likely explanation is that the unequal exposure of this posterior pole results in localised surface stresses being set up which give rise to the wrinkled area.

Saldula brevicornis

This species was reared through all stages in the laboratory using the technique already described. The eggs were incubated at 24° C. and 100% humidity. At two days the eggs became yellowish and eyespots began to show. At three days eyespots were large and prominent. The first instars emerged at five days and fed readily. These moulted at three days. The second instar moulted after another three days. The third, fourth and fifth instars took four days each. There was definitely no post-natal moult, such as occurs in the Hebridae and other closely related families.

The first instar is of a light brownish colour with prominent yellow eyes. The first, second and third antennal segments are slender and approximately equal in size. The fourth segment is somewhat longer and much expanded. There is a prominent, light-coloured, Y-shaped line, extending forward from the first abdominal segment to the head along which splitting occurs during ecdysis. The pronotum has a transverse groove extending nearly its whole width. This is

composed of three definite curves. There is a red-coloured repugnatorial gland closely underlying the dorsal surface of the abdomen. The legs are approximately equal, the hind pair being somewhat longer. There is only one tarsal segment.

The second instar is slightly darker. The fourth antennal segment is proportionately not so large as in the first instar, but nevertheless is considerably larger than the third segment. The mesonotum has a slight transverse depression. The edges of the thorax and abdomen are slightly explanate. The third abdominal tergite has a rounded projection posteriorly at its mid-point. This is apparently connected with the bland mentioned in the first instar. The hind legs are slightly longer than the other pairs but only possess one tarsal segment.

The third instar is brownish with a prominent light-coloured suture. The fourth antennal segment is larger than the others. The sides of the thorax and abdomen are definitely explanate. The meso- and metanotum have started to expand posteriorly. The hind tarsi show the differentiation of the first tarsal segment.

The fourth instar is dark-coloured with a prominent light-coloured suture. The head shows the three pairs of bristles characteristic of the adult. The third and fourth antennal segments are equal in length and are somewhat shorter than the second. The pronotum and mesohotum show further differentiation. The lateral edges of the pronotum are explanate, the posterior edge is flat and the callus is well developed, and shows the depressions that form the fovae. The mesonotum shows further differentiation. The wing-buds are well developed and the central portion shows characteristic contours. The abdomen has explanate sides. The third abdominal segment shows the same structure as earlier mentioned. The hind legs are much longer than the front. The tarsi of the fore, mid and hind legs show the differentiation of the first tarsal segment.

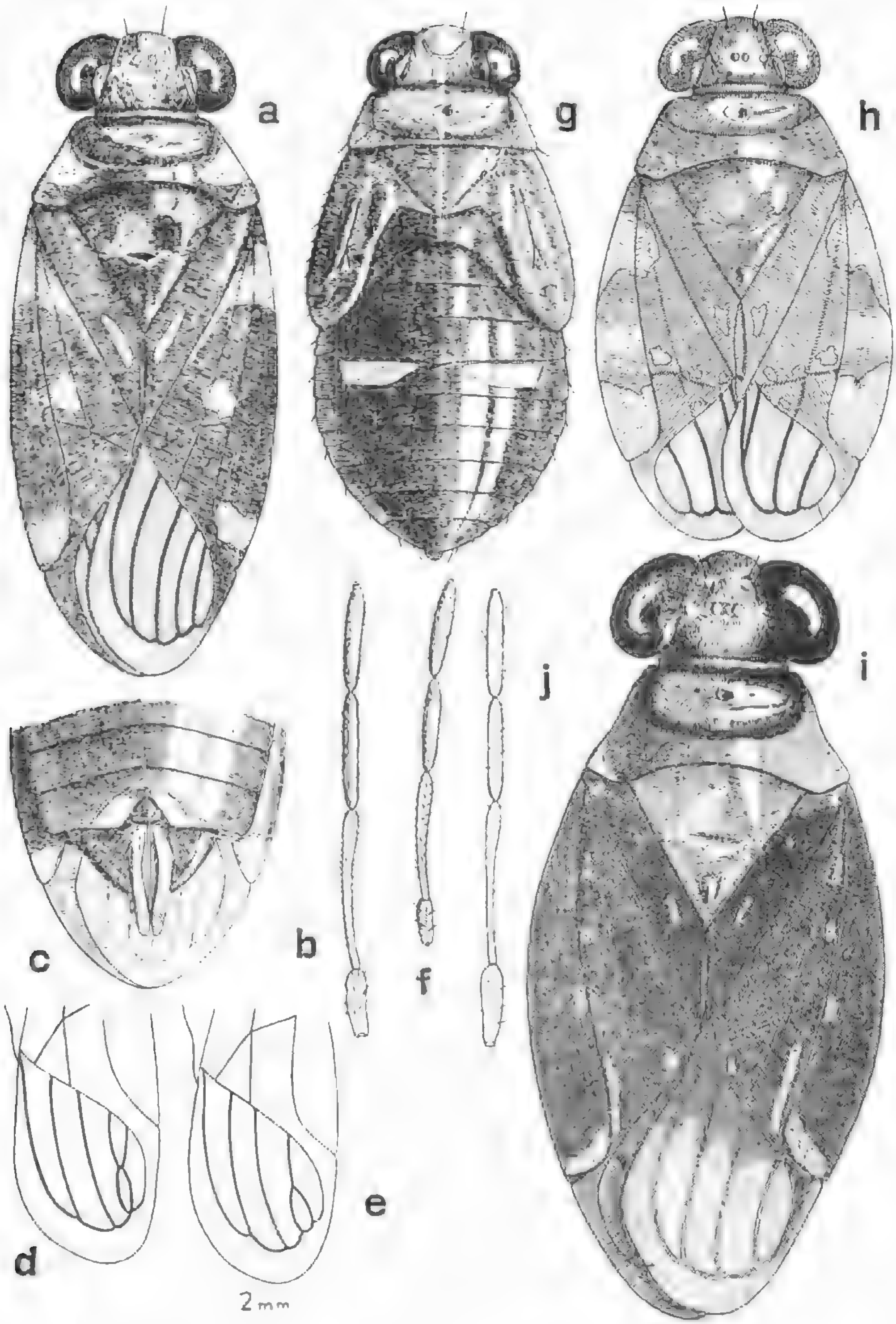
The fifth instar is much larger than the fourth, being only a little shorter than the adult. It is dark-coloured with a definite white pattern. The eyes are more prominent than in the previous instar. The second antennal segment is longer than the third and fourth which are equal. The two diverging grooves which run just in front of the ocelli in the adult are present. There is a dark polygonal patch between the eyes. The pronotum is similar to that of the fourth instar. The mesonotum is complexly contoured and has three pairs of definite white patches on the central portion. The wing buds are further developed. The metanotum has extended further back, the posterior tips of the meso- and metanotum coinciding. The abdomen has explanate lateral edges, the third abdominal segment showing the structure earlier described There is a definite colour pattern. The hind legs are much longer than the other pairs, the first tarsal segment being the only one differentiated, although the region of the second and third is closely shown by the colour pattern.

Saldula coorongensis

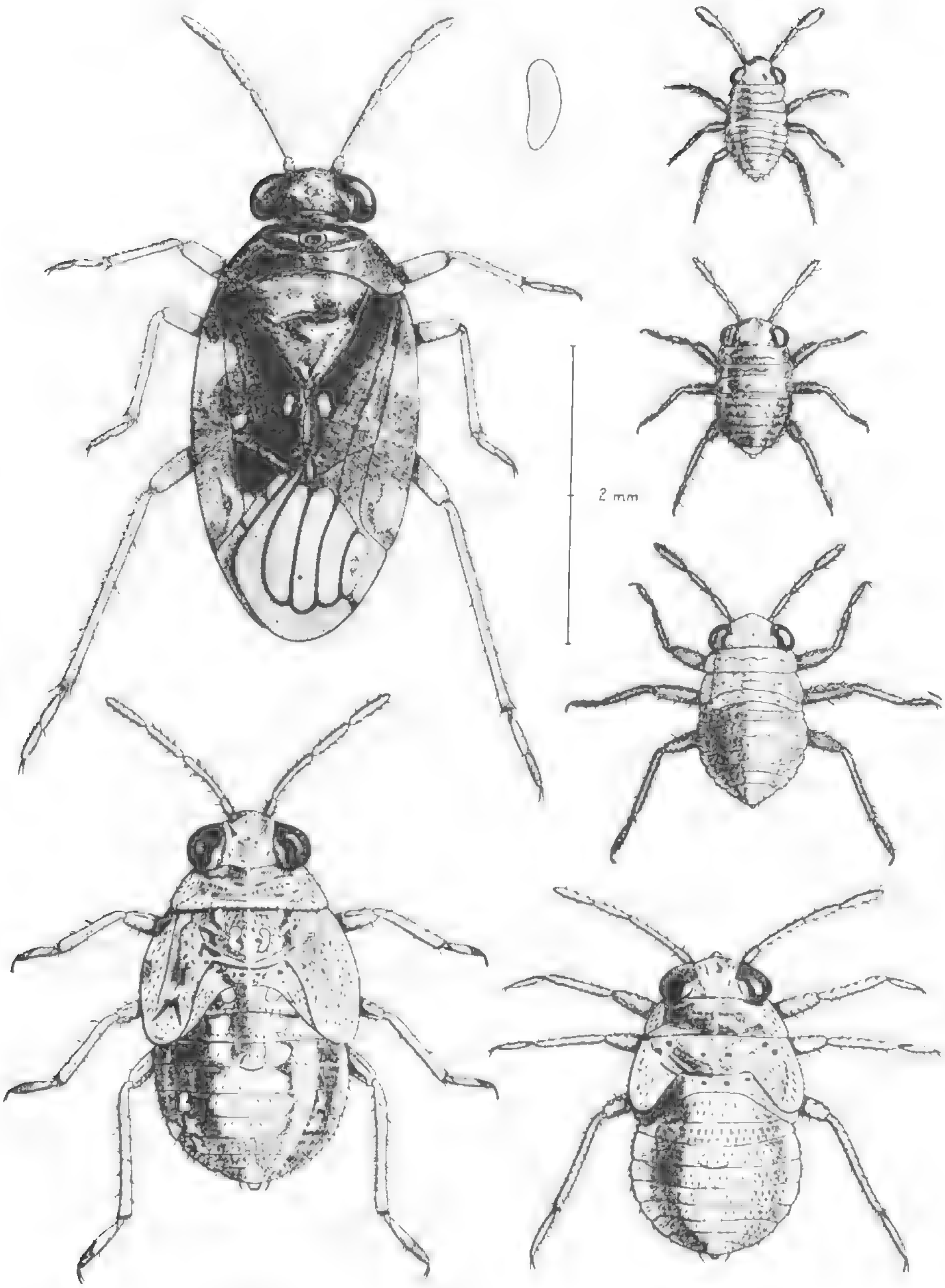
Eggs were obtained from specimens kept in the laboratory and incubated at 27° C. and 100% humidity. Time of hatching was five days. The instars resemble very closely those of *S. brevicornis*.

Saldula psammobia

The instars do not differ significantly from those of *S. brevicornis*, except for the fifth which lacks the elaborate pattern of this species, the body surface being brownish-black or light brown. There is a prominent light-coloured Y-shaped suture line present.



A, *Pentacora leucographa*, adult male. B, Antenna. C, Ventral surface of female. D, E, Variations in membrane. F, Antenna, fifth instar. G, Fifth instar. H, *Saldula psammobia*, brachypterous form. I, *Salda nicholsoni*, adult male, with antenna J.



Saldula brevicornis. Adult male, egg, and the five instars.

PENTACORA LEUCOGRAPHA

The instars of this species occur in the field with those of *S. psammobia.* They are easily distinguished from the latter by the presence of two large white patches on the fourth abdominal segment, these occurring in all instars.

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A NOTE ON THE LIFE HISTORY OF THE AUSTRALIAN FRESHWATER MUSSEL, HYRIDELLA AUSTRALIS LAM

BY I. D. HISCOCK

Summary

The life-history of the Australian freshwater mussel, Hyridella australis Lam. is recorded.

A NOTE ON THE LIFE HISTORY OF THE AUSTRALIAN FRESHWATER MUSSEL, HYRIDELLA AUSTRALIS LAM.

By I. D. Hiscock*

Communicated by T. Harvey Johnston

[Read 9 November 1950]

SUMMARY

The life-history of the Australian freshwater mussel, *Hyridella australis* Lam. is recorded.

The glochidium is hookless and wi'! parasitize *Gambusia* (lightly); the callop, *Plectroplites ambiguus* (heavily); but not the carp, *Carassius auratus*. The callop is probably the principal natural host of the glochidium. The larvae attach themselves to the fins but not to the gills and remain on the fish for twenty-two to twenty-three days at 20° to 22° C.

From the discovery in 1832 by Carus that the glochidium, for a long time accepted as a parasite infesting the gills of freshwater mussels, was the larva of the mussel itself, and from that of Leydig in 1866 that the glochidium, after liberation from the parent, completed its development as a parasite on fishes, the life-history of many freshwater mussels has been successfully investigated. The literature published up to 1910 has been summarised by Lefevre and Curtis (1912), who investigated 37 species of American freshwater mussels. Of the life-history of the many Australian mussels little is known, and the author has found none recorded in the literature.

Routine collections by the Zoology Department of aquatic molluscs from the lower River Murray and its swamps have yielded several hundreds of specimens of *Hyridella australis* Lam. These are usually placed in glass dishes and examined for the liberation of cercaria, prior to storing in outdoor aquaria as stock for research purposes. From time to time, female specimens have been observed to extrude embryos from early gastrula to free glochidium stages while under examination in the laboratory. In November 1949 an attempt was made to study the parasitic stage in fishes. The results of this study are reported below.

Latter (1891) found that with the mussels *Anodonta* and *Unio*, glochidium larvae were extruded only in the presence of a fish, though he noted abortion of pre-glochidial stages. Lefevre and Curtis (loc. cit.) have never encountered a single instance in *Anodonta* but found the occurrence fairly common in *Unio complanatus* and in *Quadrula*. They concluded that premature extrusion was probably due to imperfect aeration of the aquarium water.

Abortion has been found to occur in about 1-2% of the collected specimens of *H. australis*. The extrusion of embryos, whether abortive or normal spawning, is similar and has been described elsewhere (Hiscock, 1950). The embryos, in strings of mucus, adhere to the mussel itself or sink to the bottom of the aquarium. The presence of whole or chopped-up fish caused no observable reaction in free glochidium larvae.

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The glochidium

The embryos remain enclosed in their vitelline membrane until the mature glochidium stage is reached. Fig. 1 shows a late glochidium enclosed in its membrane, which has no micropyle. The cilia shown at the posterior end were active and probably serve to circulate water within the membrane. Slow opening and closing of the shells was observed in a number of the late glochidia. The rupture of the membrane was accomplished by more active movement of the shells.

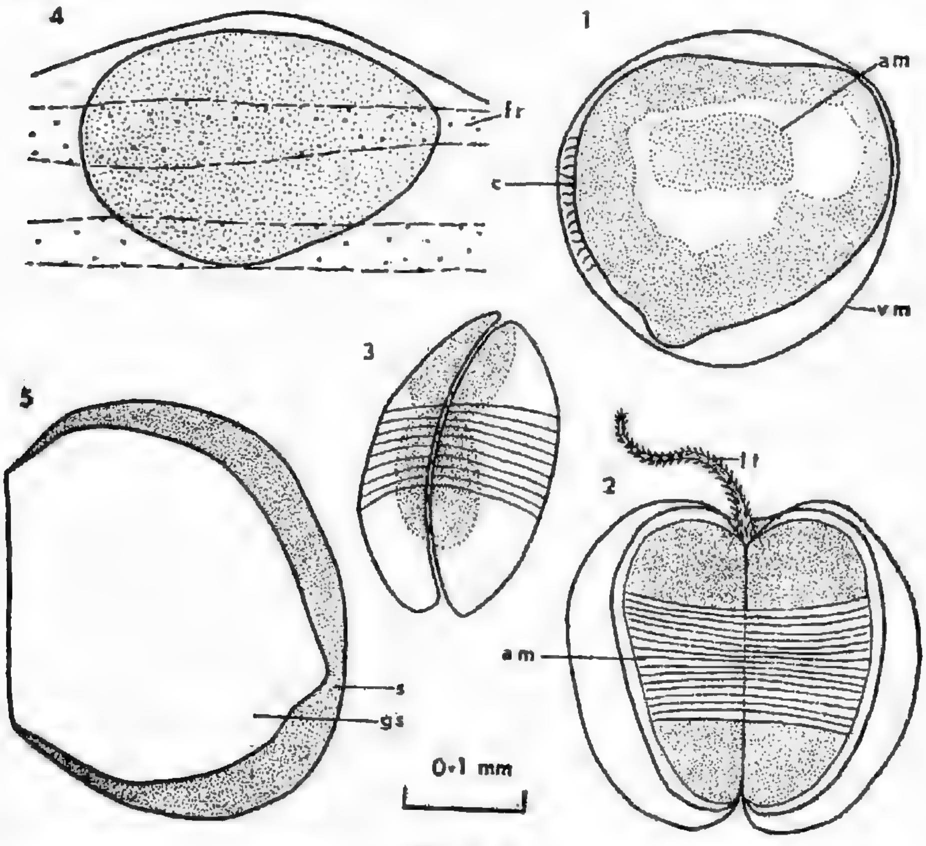

Fig. 1-5

1, A late glochidium in its vitelline membrane. 2, Free glochidium, living, seen from below. 3, Free glochidium, stained, from above. 4, Glochidium in the caudal fin of *Gambusia*, seven days after infection. 5, Glochidium, five days after liberation from the fin of a callop.
am, adductor muscle; c, cilia; fr, fin-ray; gs, glochidial shell; lt, larval thread; s, shell proper; vm, vitelline membrane.

The free glochidia were hookless and possessed a typical large adductor muscle and larval thread (once regarded erroneously as a provisional byssus). The cilia were no longer active and the shells gaped widely apart. Camera lucida drawings of living and stained glochidia are shown in fig. 2 and 3 respectively.

The parasitic stage

Free glochidia were placed in aquaria with three available species of fish, *Gambusia;* callop, *Plectroplites ambiguus;* and carp, *Carassius auratus.* All three species of fish were observed to take large numbers of larvae into the mouth and many passed out through the gills. Within half-an-hour some larvae had

attached themselves to the fins of *Gambusia* and the callop, and within two hours the fins of the callop were heavily parasitised with about one hundred larvae. No larvae attached themselves to the carp. Hourly inspection of the gills of all the fish showed that no larvae had attached themselves in this site.

Gambusia were preserved at approximately four-day intervals for more detailed inspection of the parasitic larvae. By the end of twenty-four hours the epithelium of the fin had completely overgrown the larvae, which were still easily visible on the fin margins. Fig. 4 shows a glochidium in the caudal fin of *Gambusia*, seven days after infection. It may be noted that *Gambusia* is an aquarium fish in South Australia; the golden carp, an introduced species, is abundant in the lower Murray and its swamps, while the callop is a native fish.

The post-parasitic stage

Between the twenty-second and twenty-third days after infection all the larvae had become liberated and were collected from the bottom of the aquaria. The water temperature during the parasitic period under observation remained between 20° and 22° C. About one hundred metamorphosed larvae were recovered, mainly from the callop, and were similar in appearance to those figured by Lefevre and Curtis (loc. cit.) for *Lampsilis ligamentina*. New shell growth showed beneath the glochidial shell, the mantle was well developed, and locomotion was accomplished by means of a long ciliate foot. The larvae were placed in shallow dishes on mud taken from the River Murray and daily inspections were made. Fig. 5 shows an outline drawing of a larva five days after liberation from a callop. None was found living after seven days.

Records of the finding of glochidia on fish taken from the lower River Murray have been kept in the Department of Zoology since 1938. Most of the larvae have been observed on the callop, but from the gills, not the fins. Though this is not in accordance with the findings recorded above, it is possible that these glochidia were merely entangled in the gill mucus. The following fish have been observed as hosts of glochidia: callop, *Plectroplites ambiguus;* Murray cod, *Oligorus macquariensis;* congolli, *Pseudaphritis urvillii;* smelt, *Retropinna semoni;* silver perch, *Therapon bidyana;* and catfish, *Tandanus tandanus.* The fish were collected between the months of September and February and in May, but no collections were made in any year between May and September. As no freshwater fish have been examined during that period, it cannot be stated with certainty that no glochidia are present during the winter months. It is probable that the callop is the principal host of the glochidium.

ACKNOWLEDGMENTS

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GRANITES OF THE PALMER AREA AND ASSOCIATED GRANITIZED SEDIMENTS

BY J. H. RATTIGAN AND C. F. WEGENER

Summary

The rocks discussed outcrop in the vicinity of the township of Palmer, Hundred of Tungkillo, South Australia.

GRANITES OF THE PALMER AREA AND ASSOCIATED GRANITIZED SEDIMENTS

By J. H. Rattigan and C. F. Wegener*

[Read 9 November 1950]

Contents

I. SUMMARY

The rocks discussed outcrop in the vicinity of the township of Palmer, Hundred of Tungkillo, South Australia.

Evidence is strongly in favour of the granites at Palmer having arisen through granitization of sediments *in situ*. Further, it is considered that the processes active at Palmer are connected with those which have wrought extensive regional metamorphism and metasomatism on the rocks of the eastern Mt. Lofty Ranges. The Palmer district is but part of this province of regional metamorphism and granitization.

II. INTRODUCTION AND PREVIOUS INVESTIGATIONS

The area lies 40 miles north-east of Adelaide and comprises some 35 square miles of country south of the main Adelaide-Mannum road in the vicinity of Palmer. It includes portion of the eastern escarpment of the Mt. Lofty Ranges together with a small area of the adjacent "Murray Plains" west of the Monarto-Sedan railway.

In this paper most attention is given to the two main granitic outcrops namely, (1) the Palmer Granite and (2) The Rathjen Gneiss. The former is the larger and occurs nearer Palmer township, while the latter lies a few hundred yards to the west of the Palmer granite and is much less conspicuous.

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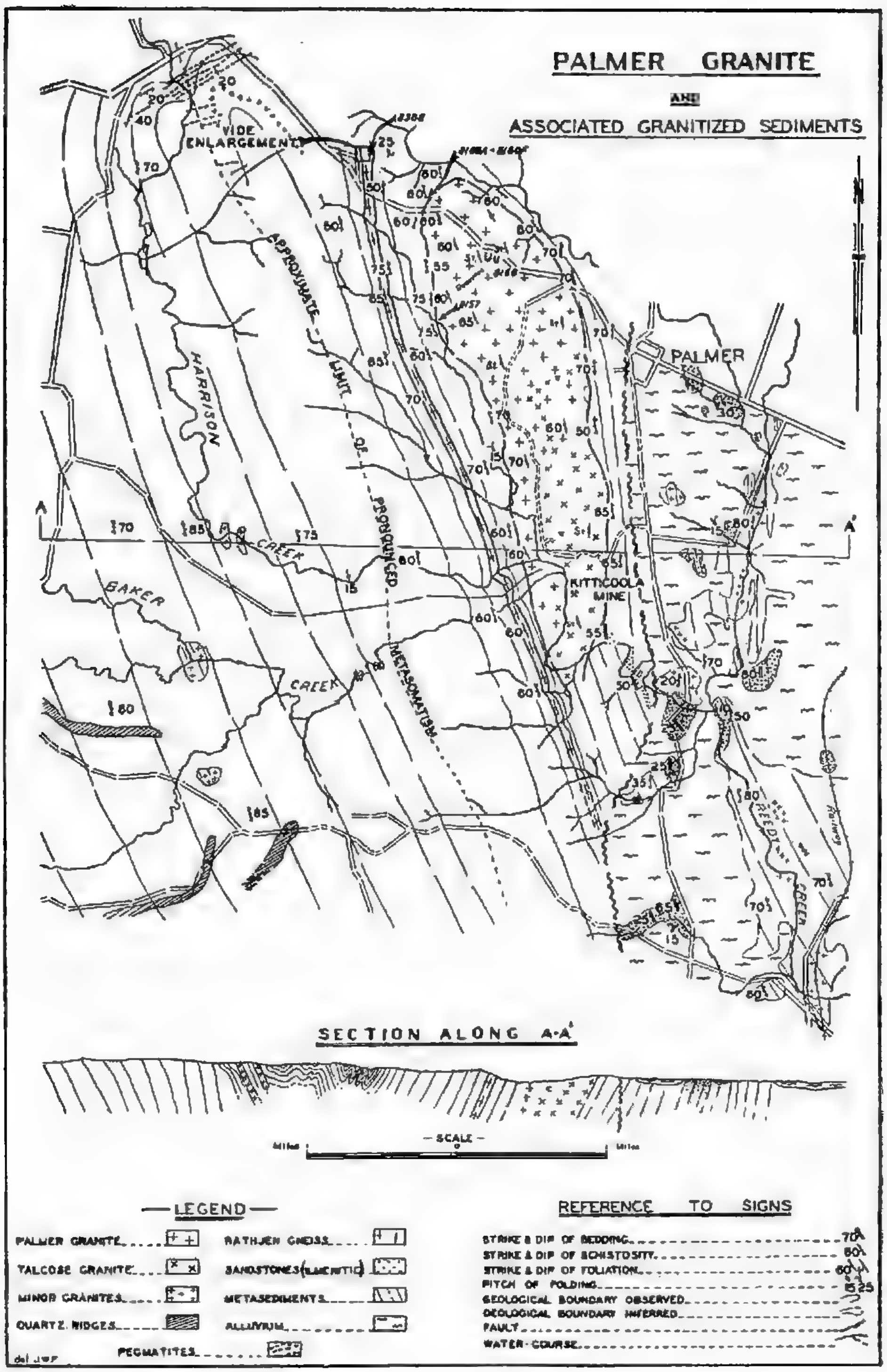

Fig. 1

General Geological Map.

No detailed geological work has previously been undertaken in the area. Several writers have, however, dealt in some measure with parts of it. Hossfeld (1935) dealt with the areas north and west of Palmer and briefly with the Palmer granite. Jack (1923) examined the Palmer granite mainly with regard to its utilisation as a building stone and in his report a chemical analysis of the granite by W. S. Chapman is recorded. A short report by H. Y. L. Brown (1903) dealt with the Kitticoola Mine mainly from a mining and economic aspect.

The location of rocks especially referred to in the text is indicated by specimen numbers shown on the accompanying map of the area (fig. 1).

III. PHYSIOGRAPHY

The most prominent physiographic features in the vicinity of Palmer are the eastern escarpment of the Mt. Lofty Ranges, here known as the "Palmer Hills," and the "Murray Plains" immediately to the east. The hills rise abruptly out of the plain along the line of the escarpment fault which runs in an approximately north-south direction on the western side of Palmer township.

The Murray Plains comprise gently undulating country stretching eastwards from the fault line to the River Murray. The plains west of the Monarto-Sedan railway are mantled with alluvium for the most part through which project numerous outcrops of older granitic rocks and metasediments. A thin discontinuous capping of ferruginous fluviatile grits of Tertiary age is occasionally observed at the surface. East of the railway, inliers of the tonalitic rocks are prominent together with other granitic rocks and metasediments. Further eastwards, towards the River Murray, fossiliferous Tertiary marine limestones outcrop extensively.

The Palmer Hills rise abruptly out of the plains and their present elevation is due to block faulting in the late Cainozoic "(?) Kosciuskan Epoch." They have been transected by several east-flowing creeks (Baker, Harrison, etc.), which have cut steep gorges through the country rock near the fault line. These creeks join Reedy Creek in the vicinity of the Kitticoola Mine, and this creek passes out of the hills onto the plains and flows in an easterly direction towards the River Murray. The surface nature of the hills area is very rough and stony. Granite tors of varying size are numerous in the north-eastern sector while elsewhere the "bedded" schists and gneisses project prominently above the ground so that the line of strike can be traced visually for considerable distances. In the absence of trees and with a paucity of soil covering, the Palmer Hills are in strong contrast with those nearer Tungkillo west of this area.

IV. GENERAL GEOLOGY

1. Structure

The country rock has been folded into a major unsymmetrical syncline pitching gently in a south-south-west direction. Minor folding within the major structure is often highly complicated, especially near the supposed base of the syncline where tight folding has been intense. The general form of the structure in section is illustrated in fig. 1.

Much of the eastern escarpment is occupied by a major crush zone. This attains a considerable width in the vicinity of the Kitticoola Mine where it measures approximately three-quarters of a mile. Forking of the ancient fault to the south of Kitticoola is probably the cause of the broad crush zone. The general trend of faulting is in a roughly north-south direc-

tion. Although the present elevation of the scarp is attributed to faulting in the late Cainozoic, the original faulting occurred probably during the early Palaeozoic era to which much of the fault crushing is attributed. The original fault must have post-dated the Palmer granite, as the granitic rocks involved are shattered and veined. Subsequent mineralization of the shatter zone caused widespread metasomatic changes within the granite and was responsible for the introduction of vein quartz, specular haematite, pyrites, arsenopyrites and carbonate minerals. In the Kitticoola region especially, gold and ore minerals of copper also achieve considerable importance. The replacement origin of the Kitticoola ores is suggested by the existence of doubly terminated quartz crystals. Shattering of granitic rocks and metasediments alike has been considerable and polished shear surfaces with slickensides are common. Rejuvenation along the older fault lines occurred in the late Cainozoic. This rejuvenation is evidenced by the bold prominence of the scarp and the steep gorges cut through it, as contrasted with the low-lying areas to the east. Further evidence of the uplift is seen in the differential elevation of the Tertiary fluviatile grits and conglomerates, which occur both on the plains and at high levels in the hills. On this basis the relative vertical movement was approximately 700 feet.

2. Country Rock — Sediments and Metasediments

Considerable metamorphism and metasomatism has occurred throughout the region and apart from small areas of felspathic sandstone in the south-eastern sectors, the original sedimentary rock types are rarely revealed.

The felspathic sandstones occur on both sides of the fault, the more kaolinised variety occurring on the plains and the more quartzitic variety in the faulted area. The high ilmenitic content of many of these rocks is a most interesting feature from both the stratigraphic and petrologic points of view. This mineral occurs as numerous thin bands throughout the rock, but in some cases may attain a width of up to a foot. A comparison of bedding, as delineated in the sandstones by the ilmenitic bands, with schistosity in the adjacent rocks, reveals that the schistosity, in close proximity to the sandstones at least, is sensibly coincident with the original bedding. Metasomatised variants of the ilmenitic sandstones, in the form of rutile-bearing anthophyllite-quartz schists and also containing parallel bands of ilmenite, are met with on the plains. Although exposures of both the ilmenitic sandstone and ilmenitic anthophyllite-quartz schist are scattered, they are abundant enough to suggest that much of the plains area under consideration here is underlain by this rock type. A northerly extension has also been recorded by Hossfeld (1935). Two other occurrences of anthophyllite-quartz schists were exposed in cuttings along the main Mannum-Adelaide road. One lay immediately west of the Rathjen Gneiss and the other on the eastern side of the synclinal nose in the north-west of the area. Both of these displayed very minor amounts of ilmenite.

Other rock types outside the migmatitic zones comprise mainly quartz-felspar-mica schists, granulitic quartz-felspar rocks and thin beds of dark amphibolitic rocks.

3. Granitic Rocks

A. Palmer Granite

The Palmer granite comprises the major portion of the granite area, covering a little more than two square miles of country immediately west of Palmer township. The main Mannum-Adelaide road cuts across it at its greatest width, but the Granite does not extend far north of this road.

This granite has a distinctive spheroidal mode of weathering which has given rise to tor-strewn hills, so much a feature of the landscape on both

sides of the main road (pl. xi, fig. 1). The tors range up to thirty feet or more in diameter and their mode of formation is well illustrated in the concentric cracks observable on the face of a road metal quarry some one and a half miles west of Palmer.

(1) *Shape of Outcrop*

The outcrop is lenticular and elongate, trending in a general north-south direction. It is approximately three and a half miles long and one mile at its maximum width, near the northern end, and tapering somewhat to the south.

Although a certain amount of discordance appears to be present, actual contacts are almost completely lacking due to surface soil cover and hence close study of these was not possible. The granite body, however, shows general concordance with the metasediments and its margins are for the most part roughly parallel with the near north-south strike of the metasediments. On the north side of the main road the margin for several hundred yards does bear discordant relations with the strike of the metasediments.

(2) *Nature and Variability*

Traverses across the granite from east to west reveal two notable features. First, the granite is extremely variable as regards appearance, grain size and other textural characters, relative proportions of component minerals, mode of weathering and jointing, and in the degree in which foliation has been developed. Secondly, the more prominent varieties trend in conformity with the margins of the outcrops, that is, generally parallel with the strike of the adjoining metasediments.

The most prominent variety is the coarse pink microcline granite in which the tor structure is best developed. This is one of the few varieties considered to resemble magmatic granite. It has a tendency to be porphyritic with microcline crystals often attaining a length of two centimetres. In thin section the texture of a typical *Palmer Granite* (8168) may be said to resemble the crystalloblastic type more than the pyrogenetic. Quartz is abundant as crystals of variable size and irregular outlines. Microcline displays the typical "crosshatched" structure, and peculiar skeletal intergrowths of quartz may be seen in certain crystals. Plagioclase is not notably inferior in abundance to the alkali felspar. It occurs as slightly clouded colourless crystals of low positive relief. Alteration is often most intense within a central kernel, the outer portions of the crystals being clear. The maximum extinction angle in a plane perpendicular to 010 is 5°, which corresponds with an oligoclase of composition near $Ab_{80}An_{20}$. Myrmekitic intergrowths of quartz in plagioclase are occasionally seen. Biotite is not abundant but is an intensely pleochroic variety; $X =$ yellow, $Y = Z =$ deep brown (almost opaque). Ilmenite and sphene are notable accessories occurring in association with one another. The sphene is leucoxenic in nature and is apparently derived from the associated ilmenite. Apatite is also abundant in accessory amounts.

A chemical analysis of this rock (8168) was made by J. H. Rattigan and this, together with the norm, are tabulated herewith.

SiO_2	74·62
Al_2O_3	13·91
Fe_2O_3	1·18
FeO	·92
MnO	—
MgO	·55
CaO	1·61
Na_2O	3·15
K_2O	3·56
H_2O+	·25
H_2O-	·14
TiO_2	·32
P_2O_5	·08
S	·04
	100·36

NORM:

Quartz			38·40
Orthoclase			21·3
Plagioclase	Ab	26·72	34·23
	An	7·51	
Corundum			2·04
Hypersthene	Fs	·26	1·66
	En	1·40	
Magnetite			1·62
Ilmenite			·61
Apatite			·20
			99·89

Among the numerous other varieties of granitic rocks in the Palmer Granite are a porphyritic microgranite, a compact greasy grey quartzose type, a pink aplitic granite and a pink granite gneiss containing a considerable amount of hornblende. A coarsely gneissose red granite is prominent near the Kitticoola Mine. This is also subject to some variations in mineral composition, but this is attributed to later pneumatolytic processes.

In a report on the quality of the granite as a building stone, R. L. Jack (1923) also mentioned the variability in nature of this rock. He found it difficult to reconcile the strongly sheeted nature of the aplitic variety as observed in the road-metal quarries, with the adjacent tor structure in the coarser granite. He could not envisage both types as arising from a single magma and subjected to the same conditions in later time. In explanation Jack proposed a "dyking" hypothesis whereby a younger granite was supposed to have dyked an earlier one. The present wider and more intensive field studies suggest that this theory cannot be supported.

Metasomatic Variant of the Palmer Granite—Along the eastern ridge of the escarpment an abnormal phase of talcose granite extends from just west of Palmer township southwards to Kitticoola and Reedy Creek. Occurrences of this granite may be readily distinguished by its angular, jagged and blocky mode of weathering which contrasts strongly with the tor structure of the adjacent normal granite. The abnormal granite has been shattered and fractured as a result of faulting, presumably during an early Palaeozoic epoch. The infilling of the fissures by secondary quartz, haematite, pyrite and rarely chalcedonic silica and calcite is characteristic. Polished shear surfaces and slickensides are a feature and are often outlined in quartz or haematite. The blocky mode of weathering is a consequence of the shattering and secondary veining.

From a study of this granite on the Kitticoola ridge and its relations with the coarsely gneissic red granite type, which outcrops immediately to the west, it is apparent that the abnormal granite is a metasomatic variant of the normal granite. All gradations from the coarsely gneissic red granite to a pink and green talcose granite may be observed along the banks of Reedy Creek in the vicinity of the Kitticoola Mine. The biotite and plagioclase can be seen in all stages of alteration. The red microcline is relatively unaffected. The textures of normal and abnormal types are identical except where veining with secondary silica has interfered.

Field study leaves little doubt as to the origin of the talcose granite, namely, through replacement effected in the normal granite in the crush zone. Petrographic evidence supports this. Pegmatites within the granite have also suffered similar alteration to talcose types.

(3) *Internal Structures and "Xenoliths"*

The gneissic structure of the Palmer granite is recognised mainly by the parallel orientation of biotite, and also hornblende in varieties on the western side of the outcrop. In one group of granitic rocks, namely the grey microgranites, this parallel structure would be more appropriately termed schistosity. In some coarser granites, however, such as the red Kitticoola granite, segregation of biotite flakes has resulted in a pronounced foliation structure being developed. The strike of gneissosity is in general parallel with the strike of schistosity in the adjoining metasediments except where local distortion occurs, possibly due to original minor folding in the transformed sediments.

Dark schistose "xenoliths"[1] are numerous within the granite, varying in size from an inch to several feet in diameter. They are seldom found lacking in any portion of the granite, even in the central portion, where they are no less abundant than near the contact. In nature they are fine-grained and usually biotite-rich, which gives them a marked schistosity. Their form is usually ovoidal, or elongated and ellipsoidal with smooth edges, and they are not the jagged, irregular assortment so often a feature in an injected magma whose upward movement has been assisted by stoping. The longer axis and also the schistosity of these "xenoliths" are almost invariably orientated parallel with the direction of foliation in the granite. The more basic types of "xenoliths" are thought to be basified remnants of country rock still remaining after transformation of the remainder of the sediments. Lighter types are common although not so conspicuous as the darker varieties. They are usually fine-grained in nature and often schistose, but grade into "ghost remnants" almost identical in mineral composition with the granites. These "ghost structures" are less regular in shape than the more conspicuous basic "xenoliths". They also preserve the same general orientation and conformity with the foliation and often weather more readily than the enclosing normal granite.

(4) *Observations about the Contact*

The margins of the Palmer Granite are for the most part roughly parallel with the strike of the adjacent country rock. The area previously mentioned on the north side of the main road is the most prominent exception and here there are discordant relations with the strike of the surrounding rocks for several hundred yards of the contact. Exposures in the immediate vicinity of the contact in general are almost universally absent or very poor, due to a mantle of alluvium. One small exposure in a creek bed of an actual contact consists of a fine-medium-grained granite forming a fairly sharp contact against a hard grey even-grained granulite showing no visible schistosity. Microscopically the *granulite* (8157) has a granoblastic texture. Quartz and microcline, equally abundant, are the two main mineral constituents, plagioclase being present in accessory amounts only. Both muscovite and biotite are fairly abundant. Other accessories, all of which are prominent, are epidote, sphene, zircon, calcite, iron oxides and tourmaline.

The discordance mentioned above allowed for the collection of a series of rock specimens (8160A to 8160F) along the strike of a schist which led into the

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[1] The term "xenolith", as here used, is not in strict accordance with its common usage, but for convenience it has been used to indicate the residuals of country rock which have not been completely metasomatised.

granite. The specimens were taken at intervals over a distance of about two hundred yards. A microscopic study of thin sections of these rocks reveals the gradual mineralogic and textural changes in the transition from schist to granite.

The parent rock (8160A) of the series is a fine-grained grey *quartz-felspar-biotite-schist* with quartz and biotite in obvious abundance. Segregation of the biotite is not particularly noticeable in the hand specimen. Microscopically it has a granoblastic texture, somewhat modified by the more or less parallel alignment of the biotite. Grain size is of a fine and uniform nature. Quartz is very abundant and fairly clear. Biotite is also abundant and shows definite directional structure. The plagioclase is an oligoclase of composition near $Ab_{80}An_{20}$, but rarely shows twinning. Only a small amount of microcline is present, and muscovite, apatite, zircon, tourmaline and ilmenite occur in accessory amounts.

Specimen 8160B is somewhat darker and more compact macroscopically, with alternating lighter and darker bands. In thin section the layers of muscovite are numerous and closely spaced. Crystals of this mineral are now larger and more idioblastic. Biotite occurring in the muscovite layers shows slight alteration to chlorite. Tourmaline crystals are now much larger and unusually abundant.

Specimen 8160C is somewhat lighter and slightly coarser in appearance than 8160B. Microscopically, directional structure is less marked and grain size is more variable. Plagioclase is more abundant but still commonly untwinned. It is an oligoclase of composition near $Ab_{75}An_{25}$. Muscovite is less abundant but biotite is on the increase. Tourmaline is much less abundant and only occasional crystals occur.

Specimen 8160D is a *bimica-quartz-plagioclase migmatite*. Macroscopically it is a coarser looking rock which has suffered slight local folding and is richly biotitic. The strongly biotitic bands alternate roughly with quartzo-felspathic bands. Several small crystals of apatite were seen embedded in biotite-rich bands. In thin section both biotite and muscovite show segregation along somewhat contorted lines. Potash felspar is still absent but quartz and oligoclase are abundant. Apatite is a prominent accessory and zircon is still common both as detrital-like grains and as inclusions in biotite. Iron oxides occur in slightly increased amounts and commonly occur as irregular intergrowths in the muscovite laths.

Specimen 8160E is a somewhat weathered pink *granitic gneiss*. The directional structure that the biotite assumes shows evidence of residual minor rock flexures. Biotite is now much less prominent. Microscopically this rock exhibits a typical crystalloblastic texture and consists essentially of quartz and felspar with smaller amounts of biotite and other accessories. The edges of the quartz are considerably sutured and inclusions of microcline, biotite and small crystals of tourmaline are common in this mineral. Microcline is abundant as slightly turbid xenoblasts, but plagioclase is less prominent. It is still an oligoclase of composition about $Ab_{75}An_{25}$. Biotite is present in small quantity only and muscovite is almost absent. Several large xenoblasts of ilmenite are present and show slight alteration to leucoxene. Other accessories are zircon, apatite, tourmaline and orthite.

The final specimen (8160F) in the series is a fine-grained *pink granite*, slightly weathered, with an even distribution of biotite. In thin section it is essentially similar to 8160E but slightly finer-grained. Leucoxene occurs as an alteration product of ilmenite.

Modal proportions of the mineral constituents of each specimen with added discussion are given later.

Several hundred yards further east along the contact is another interesting example of a similar nature. Here several narrow bands of felspathised sandstone occur just inside an area of compact medium-grained "leuco-granite". These several bands may be traced outwards along the strike into a fairly wide series of felspathised sandstones beyond the contact.

B. The Rathjen Gneiss

The Rathjen Gneiss lies on the western side of the Palmer Granite outcrop. It has its greatest development north of the main road, but to the south it continues for several miles as a narrow belt some 200 feet in thickness, striking in a near north-south direction. It is finally faulted out by the Cainozoic fault. Only that portion on the south side of the road and for about 200 yards on the north side is considered here.

Although the dip and line of strike of the strata remain relatively undisturbed south of the road, considerable variations due to folding occur on the north side. Visible contacts are more numerous and better exposed than is the case with the Palmer Granite, and this allowed for a closer study of these. The outstanding feature is the concordant nature that this granite bears with the adjacent country rock even where close folding exists. Nor is this folding confined to the country rock, for these structures are reflected well within the granite. This is clearly illustrated in the map (Fig. 2) of portion of a contact at the northern end, drawn on a scale of 25 feet to an inch. The southern half of this sector, due to better exposures, gave the more definite evidence, and although the northern part is less definite, general field relations indicate the structure as shown.

The Gneiss is somewhat variable in nature (pl. xi, fig. 3, 4) but is typically strongly foliated and coarse-grained. The foliation, which is due to the segregation of laminae of biotite, is everywhere parallel with the strike of the adjoining rocks. The tor structure is here much modified by the influence of pronounced foliation and the outcropping rocks have rounded tops with flattened walls dipping at an angle to the ground surface in conformity with the surrounding metasediments (pl. xi, fig. 2). "Xenolithic" remnants, although not numerous, preserve their regional orientation. An example of one variety measured four feet in length by a maximum width of two inches.

A typical specimen of the *Rathjen Gneiss* (8308) was examined microscopically. It displays a coarse-grained crystalloblastic texture with marked gneissosity. Quartz and felspar are by far the most abundant constituents with biotite in lesser quantity. Sphene and ilmenite are unusually abundant as accessories and the former is often distinguishable in the hand specimen. Quartz shows much variability in size, and suturing of the edges is common. It also occasionally occurs as myrmekitic intergrowths and quite commonly as rounded inclusions, in felspar. The felspar is fairly fresh and some sutured edges are also evident here. Plagioclase and microcline are almost equally prominent. Twinned sections of plagioclase normal to 010, give a maximum extinction of 8° and with an R.I. > balsam, indicate it as an oligoclase of composition $Ab_{75}An_{25}$. The microcline is readily distinguished by its excellent "crosshatched" structure. Biotite is strongly pleochroic from nearly black to light brown and is segregated along definite parallel directions. Ilmenite occurs as large black idioblasts commonly showing slight alteration to leucoxene. Brown, slightly pleochroic idioblasts of sphene are mainly concentrated in the biotite-rich bands and are unusually abundant. Partial alteration to leucoxene is common. Apatite is also concentrated in the biotite bands, but not as abundantly as sphene. Zircon is present in small accessory amounts only, mainly as inclusions in biotite.

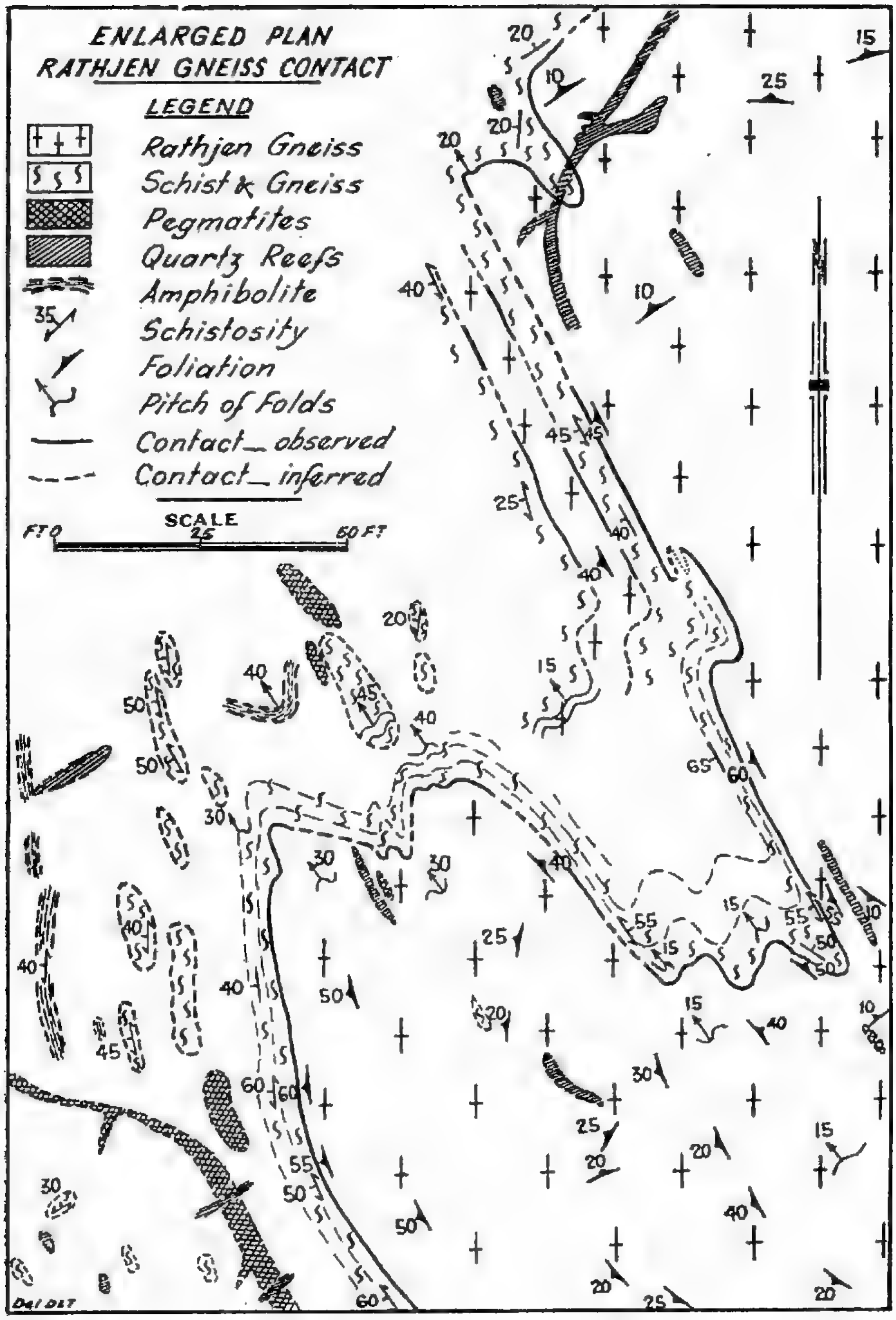
ENLARGED PLAN
RATHJEN GNEISS CONTACT
LEGEND
Rathjen Gneiss
Schist & Gneiss
Pegmatites
Quartz Reefs
Amphibolite
Schistosity
Foliation
Pitch of Folds
Contact _ observed
Contact _ inferred
SCALE
FT 0
25
50 FT

Fig. 2

Results of a chemical analysis of the *Rathjen Gneiss* (8308) by C. F. Wegener, together with its norm are given below.

SiO_2	73·05	Norm:—			
Al_2O_3	12·81				
Fe_2O_3	1·54	Quartz			35·88
FeO	2·30	Orthoclase			18·90
MgO	·64	Plagioclase	Ab	28·82	36·88
CaO	1·74		An	8·06	
Na_2O	3·42	Corundum			·71
K_2O	3·15	Zircon			·18
H_2O+	·49	Hypersthene	Fs	1·45	3·05
H_2O-	·16		En	1·60	
TiO_2	·78	Magnetite			2·32
P_2O_5	·10	Ilmenite			1·52
MnO_2	Tr.	Apatite			·34
ZrO	·09	Pyrites			·12
S	·05				
					99·90
	100·32				

C. Minor Granitic Outcrops

Outcrops of granitic rock occur sporadically among the country rock, both of the hills and the plains. They are invariably of medium and even grain but vary in colour from pink to white. Many are apparently granodioritic in nature with a notable biotite content, while others are aplitic and non-biotitic. Lineation in many of these masses is absent.

One of these granitic masses is a narrow curving band outcropping around the nose of the pitching syncline in the north-west portion of the area and again illustrates the concordance of the granitic rock with the structure of the country rock. It is a handsome white rock, granodioritic in nature, commonly streaky in appearance and containing clots and lenticles of biotite. On either side of the outcrop are saccharoidal quartz-plagioclase-biotite-schists with biotite mainly segregated into layers.

4 Other Migmatitic Rocks

The granitic rocks are migmatitic in nature but the migmatites with a less obvious granitic texture have yet to be described. These rocks include veined gneisses, compact "permeation" migmatites, contorted composite gneisses, biotite enriched schists and foliated amphibole-epidote gneisses.

The term *veined gneiss* has been applied to those rocks with a characteristic alternation of parallel quartzo-felspathic and schistose layers in preference to *injection gneiss* or *"lit-par-lit" gneiss*, which more usually presuppose injection of magmatic materials (pl. xii, fig. 1 and 2). These rocks are prominent, adjoining the Rathjen Gneiss on its western side and to a lesser degree about the Palmer Granite (mainly on the east and north-east side) and about the minor granitic outcrops. The veins of quartzo-felspathic (granitic) material vary in thickness but may range up to more than an inch. They are commonly bordered with thin layers of biotite.

The writers fail to see how actual injection could produce the remarkable parallelism so commonly seen in the adjacent granitic and schistose layers without distortion of the foliation. They consider that layers of schist have been locally transformed through permeation and granitization along the direction of schistosity to produce the characteristically veined structure.

Veined gneisses grade into the Rathjen Gneiss as the schistose layers become more granitic in texture. The strongly foliated Rathjen Gneiss is considered to represent a more intense stage of granitization than that which produced the veined rocks. The gneiss is considered to have arisen by the intimate replacement of schist along the planes of schistosity with the segregation of biotite into lenticles and layers parallel to these planes. The biotite folia which impart the foliation are considered as relicts of schistose layers equivalent to those in the veined gneisses.

In certain areas, such as along the cliffs in the lower reaches of Harrison and Baker Creeks and on the plains in the south-eastern part of the area, contorted composite gneisses are exposed. The contortions are clearly outlined by ptygmatic quartzo-felspathic veins.

The granulitic rocks adjacent to the Palmer Granite never develop a veined structure, since their close-textured recrystallized aggregate prohibits the entrance of replacing emanations along preferred directions. Coarsely foliated amphibole-quartz and amphibole-epidote-quartz rocks occur adjacent to the granite.

Close-textured even-grained crystalline rocks with no prominent parallel structure are met with between the Palmer and Rathjen bodies. These may be referred to by Read's (1948) term *"permeation" migmatite.*

The mica schists surrounding the Rathjen Gneiss on the west are sometimes marked by considerable enrichment in biotite which is segregated within the schists in planes parallel to the schistosity. The biotite may be as thin laminae or as broad sheets six feet or more in thickness. Biotite enriched schists are also observed about some of the minor granitic bodies. Outwards from the zone of granitization in each case, the segregated layers and sheets of biotite are absent from the schists. This biotite enrichment may result from the expulsion of excess Fe and Mg ions from the granitized zone into the surrounding meta-sediments.

5 Pegmatites

These range from simple quartz and quartz-microcline types, including graphic varieties, to the more complex ones carrying rare minerals. They vary in size from a fraction of an inch to several yards in width and the larger ones have been traced for a distance of more than a mile. Grainsize is usually coarse in the complex types to fine in the aplitic varieties. Grainsize may also vary within the one vein from a coarse, highly siliceous central portion, to a fine-grained margin of granitic character. Colour of the microcline is usually pink, occasionally brick red and sometimes milk white. Albite is prominent in some pegmatites. The smaller pegmatites are concordant, while the larger are more commonly discordant.

The more complex pegmatites are confined mainly to the north-west sector in the Harrison Creek area and the great majority run roughly parallel in an east-west direction. Several of these pegmatites about a mile south of the main road contain notable beryl in association with muscovite, red garnet, tourmaline and chlor-apatite. The felspars include albite in addition to microcline. Beryl crystals were found up to six inches in length and tourmaline up to one foot in length. The muscovite is a pale green variety occurring in small books only. The red garnets show well developed rhombic dodecahedral forms.

Quartz Ridges—The south-west corner of the area features several high ridges and reefs of milky quartz. These ridges rise sharply fifty to a hundred feet above the surrounding country and show up prominently as resistant level-topped masses capped in part by horizontal Tertiary grits and gravels. They have been traced for a mile or so in length and usually end abruptly.

V. ORIGIN OF THE GRANITIC ROCKS

Certain features which characterise the granitic rocks in the Palmer area are set out below.

(1) The granitic rocks are more of the nature of gneisses than magmatic granites.
(2) The granitic rocks are extremely variable in nature.
(3) The outcrops show a general concordant relation with adjacent metasediments.
(4) Foliation and orientation of "xenoliths" within the granitic bodies are also concordant.
(5) Minor structures are preserved as relicts within the granites. Structures in the metasediments near the contact are reflected well into the granitic bodies.
(6) Desilication phenomena, including basification, characterise the frontal zone around the granitic outcrops.
(7) The textures of the granitic rocks in section resemble the crystalloblastic type more than the pyrogenetic.
(8) The contacts of the granitic rocks with the metasediments are often gradational.

It is considered that these facts point to granitization in place as the process whereby the granitic rocks originated. The source rocks which have been selectively transformed to granitic rocks are believed to be sediments ranging from felspathic sandstones to greywacke, the variation in the source sediments being reflected in the type of granitic rocks now found. The purely quartzo-felspathic "leucogranite" found in the Palmer body is considered to originate from an arkosic rock, whereas the richly biotitic Rathjen Gneiss is thought to have a more impure greywacke as its source.

Because of the highly quartzose nature of some varieties of Palmer granite and the apparent trend of the ilmenitic sandstone, south of Kitticoola Mine, into the granite, consideration was given to the possibility of the granite, at least in part, being a transformation of this sandstone. As exposures were once again poor around the contact, no direct evidence could be obtained, but a granitic rock collected a short distance north of the sandstone series revealed the presence of some ilmenite in the hand specimen. A magnetic analysis of some basified "xenoliths" revealed a notable proportion of ilmenite. One case yielded 2% by weight. A microscopic analysis of many granites has also shown an unusual abundance of sphene which is invariably associated with, and apparently derived from ilmenite, since ilmenite often comprises the nucleus of the sphene crystal. Thus with the sphene content included, the amount of titania involved would have been considerable. Large sphene crystals up to half an inch in length, observed in some of the amphibolitic rocks of the migmatite zone, may represent a culmination in TiO_2 through expulsion of that constituent during transformation of the sediments. Rutile, present in some rocks, as revealed under the microscope, may also be derived at the expense of the titania content of ilmenite. A quartz reef, just east of Palmer, contained rutile crystals more than two inches long.

It is apparent, therefore, that one should not disregard the theory that the ilmenitic sandstones may be the source rocks of the Palmer Granite. Furthermore, since some of these ilmenitic sandstones are similar in appearance to the ilmenitic sandstones nearer Adelaide and recognised as belonging to the base of the Adelaide System, and considering the relatively few occurrences in the remainder of the Mount Lofty Ranges, it is suggested that they might belong to this late pre-Cambrian rock system.

Mineralogical changes occurring between the parent country rock and the granite in the series 8160A-8160F described earlier are illustrated in the variation diagram (Fig. 3) drawn up from modal proportions of mineral constituents in the separate rocks shown herewith.

Constituents	8160A	8160B	8160C	8160D	8160E	8160F
Quartz -	58·7	53·6	53·3	42·7	43·0	44·4
Plagioclase -	10·8	10·0	15·7	23·0	16·0	18·5
Microcline -	6·3	—	—	—	35·0	32·6
Biotite -	22·7	22·6	23·0	27·5	5·0	4·0
Muscovite -	·3	12·1	7·0	5·0	·1	·2
Accessories -	1·0	2·1	1·0	2·0	1·0	1·4

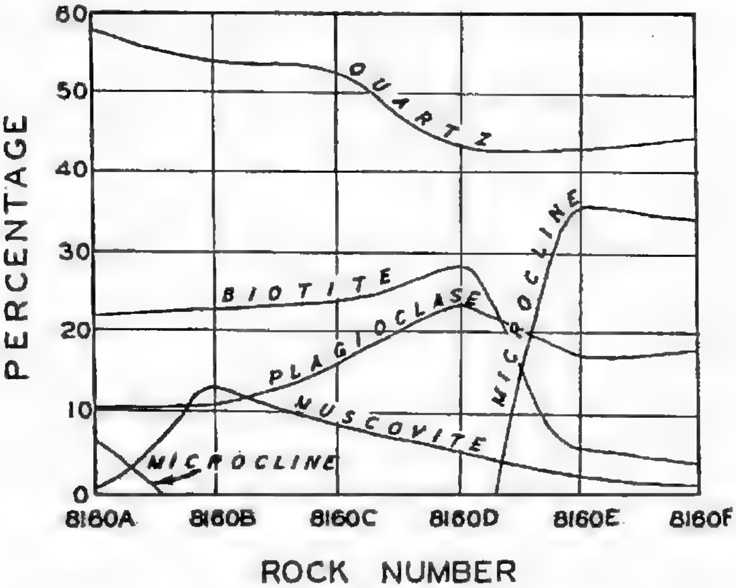

Fig. 3

Variation diagram to show change in mineral composition in transformation of schist to granite.

It can be seen from the variation diagram that desilication of the rocks at the contact is a notable feature. The most striking change is a basification process, and a geo-chemical culmination in the cafemic constituents, and also in boron and phosphorus is indicated by the increase in the modal amounts of biotite, plagioclase, tourmaline and apatite. Boron reaches its culmination in specimen 8160B and a boron "front" has apparently proceeded in advance of iron and magnesium. The granitic end of the series shows a decided increase in potash with a corresponding decrease in the femic constituents as compared with the parent rock (8160A), shown by the increase and decrease respectively in modal proportions of microcline and biotite.

The granitic rocks at Palmer, therefore, appear to have arisen by a process of ultrametasomatism through the introduction of certain constituents and the removal of others. There has apparently been a considerable influx of potash with concomitant expulsion of cafemic constituents, titania, phosphorus, etc., into the frontal zone. The activity of volatile constituents during transformation is indicated by their presence in the constitution of distinctive minerals in the frontal zone, such as boron in tourmaline, sulphur in pyrites, fluorine in

fluorapatite, chlorine and phosphorus in chlorapatite. Emigration of some silica may be indicated by the pseudo-eutectic structures of quartz in alkali felspar, since, according to Bäcklund (1946), "The emigration of silica is indicated by the wonderful implications of quartz and potash felspar. These have the appearance of eutectic structures but the proportion of quartz to felspar varies steadily."

The source rocks of the Rathjen Gneiss were probably more basic in nature than those responsible for the Palmer Granite and the transformation to gneiss was accompanied by the emigration of considerable iron, magnesium and titanium fixed in the frontal zones as biotite and iron oxides, amphibole, and sphene respectively. Numerous small crystals of iron oxide several millimetres in diameter are often concentrated in the veined gneisses adjacent to the Rathjen Gneiss.

In conformity with the granitization hypothesis, the variability of the granites is considered to be due to variability in nature and composition of the source sediments and the extent of granitization suffered by them. The leuco-granites and aplitic varieties are no doubt due to the indifferent susceptibility to granitization shown by the purer psammitic rocks in general. The idea that injection of magma should have produced such a variety of rock types seems hard to accept.

The dark ellipsoidal "xenoliths" are regarded as basified remnants of the original rocks which have escaped the general transformation to granite. They are notably richer in biotite, ilmenite and sphene than their enclosing granite.

With respect to the gneissic structure of the granitic rocks, it has been shown earlier that the foliation of the Rathjen Gneiss is considered to be a residual primary structure, the biotite folia representing the extreme case of the basified layers of the veined gneisses. In the Palmer Granite, the parallel structure is also considered a consequence of primary structures. This is supported by the essential parallelism of foliation with schistosity in both the country rock and "xenoliths". The contorted structures in the granite most probably represent relicts of original structures such as minor folding in the transformed rocks. Certain conclusions made by Sederholm (1923) regarding gneissic granites of Finland are relevant in this respect. He dismisses any dynamo-thermal action as directly responsible for some gneissic structures. He states, "where they are striped, the phenomenon is usually caused by the more or less completely resorbed inclusions of foreign rocks whose femic constituents remain as stripes of mica," and further, "when they are gneissose, this is mainly due to the fact that they have absorbed older schistose rock. The parallel texture is probably due to the assimilation of this schistose rock." Variability in the degree to which gneissose structure is developed depends on the proportion of initial femic constituents. In many of the granitic rocks at Palmer this was apparently low, some of the rocks showing negligible quantities of biotite.

VI. CONCLUSIONS

A study of the Palmer area strongly suggests that the granitic rocks have resulted from granitization of sediments in place. The area dealt with is but a small part of a much larger region along the eastern sector of the Mount Lofty Ranges and the adjacent lowlands in which similar rock types are exposed. It would appear that various features which characterise this region, namely, the folding, the regional metamorphism, the widespread pegmatization and sporadic granitization, and magmatic intrusion (as at Murray Bridge, 15 miles to the south) were all attendant upon the subsidence of Precambrian geosynclinal sediments into a high temperature region of the crust. Stresses provoked by crustal expansion initiated folding movements. Regional metamorphism occurred on a grand scale, and in favourable locations granitization was accomplished. The origin of the transforming fluids and those responsible for the widespread pegma-

tization possibly lies in the fusion at depth of easily melting portions of the sedimentary mass, and the squeezing out of such by orogenic pressure to areas where they became active. Similarly generation of magma by fusion at depth and later intrusion to higher levels may have given rise to the fluorite-bearing batholyth exposed at Murray Bridge and elsewhere.

At the present time very little detailed mapping has been done amongst these rocks of the eastern Mount Lofty Ranges and their stratigraphic position and relationships are unknown. The possibility exists that they represent regionally metamorphosed and granitized sediments of the Adelaide System but further mapping must be done before any definite conclusions can be drawn. The recognition of rutile-bearing quartz-anthophyllite schists as magnesian metasomatised equivalents of ilmenitic sandstones should also be considered in such future mapping.

VII. ACKNOWLEDGMENTS

The authors are indebted to Professor Sir Douglas Mawson, of the Department of Geology, for suggestions and facilities for the work. Our thanks are also due to Mr. S. B. Dickinson, Director of Mines, for facilities made available in the final stages of the work, and to Mr. R. C. Sprigg, Senior Geologist of the South Australian Geological Survey, for much helpful advice in the preparation of the report for publication. This investigation was in part assisted by a Federal Research Grant.

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Fig. 1
Tor-strewn landscape typical of the Palmer Granite.

Fig. 2
Exposures of Rathjen G[illegible]

Fig. 3

Fig. 4

Two varieties of Rathjen Gneiss. Darker band in Fig. 3 is a more schistose portion (slightly less granitized). Coarse granitic veins are common in parts but note that they are rarely continuous but more usually elongated lenses

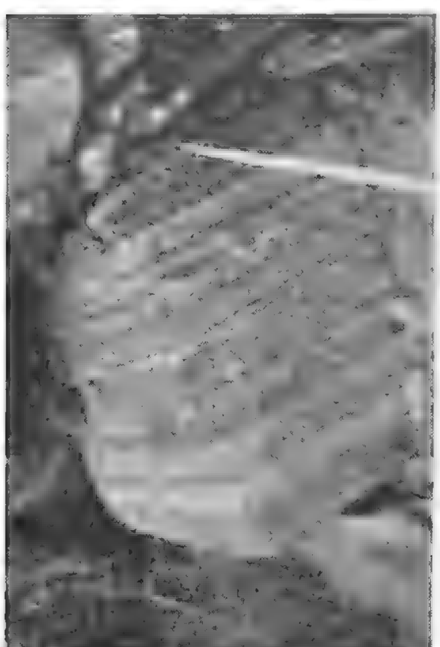

Fig. 1
Composite Gneiss.

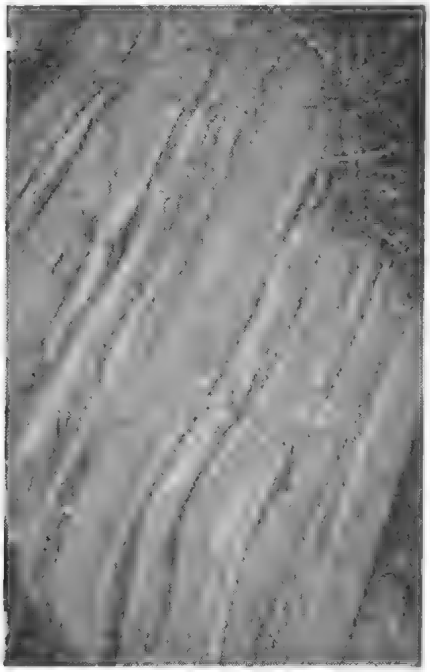

Fig. 2
Veined Gneiss.

Fig. 3
Veined gneiss illustrating a fairly advanced stage in the granitization process. Note also the dark biotitic borders to some veins.

Fig. 4
Contorted gneiss with biotitic segregations.

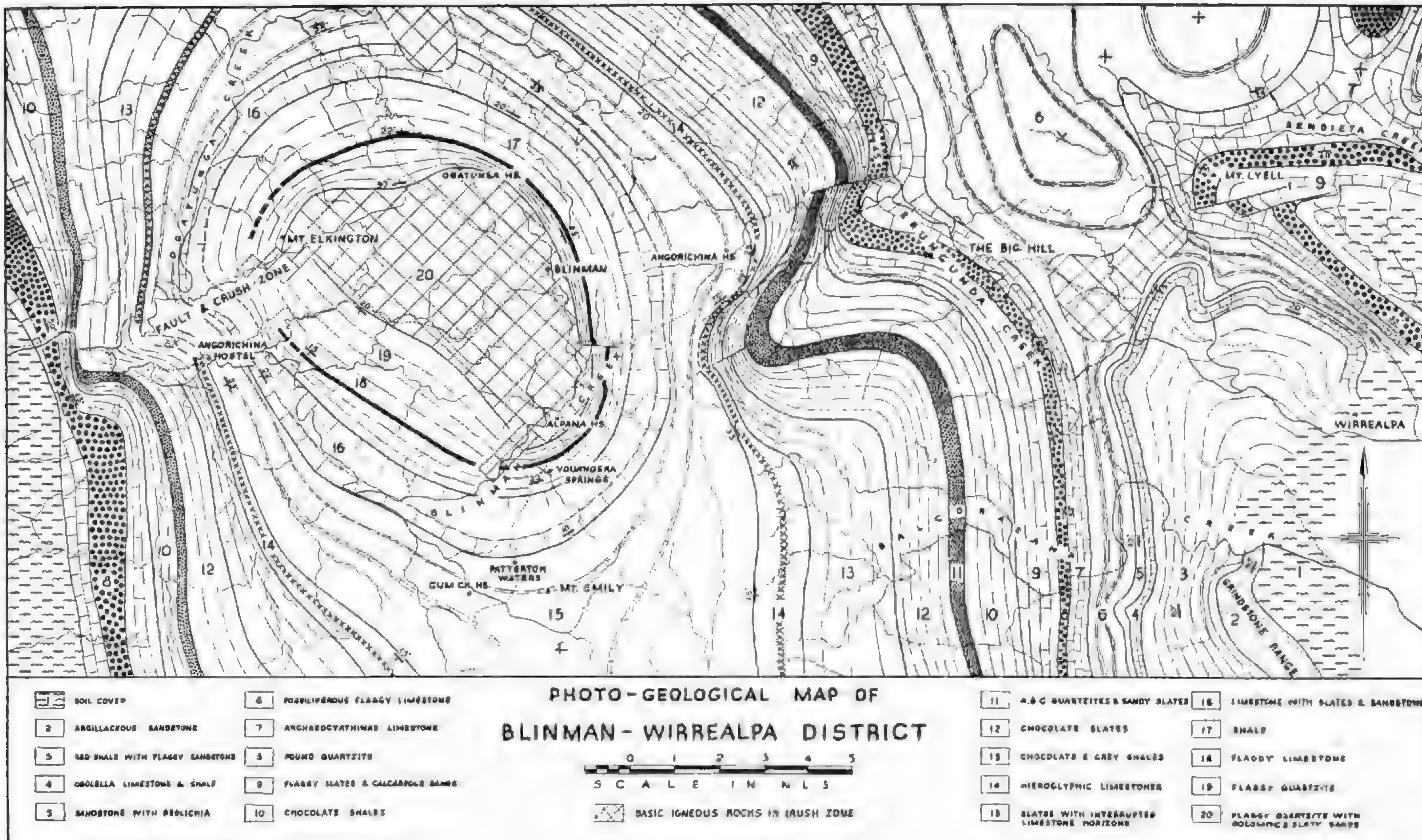
PHOTO-GEOLOGICAL MAP OF
BLINMAN-WIRREALPA DISTRICT
0 1 2 3 4 5
SCALE IN MLS
BASIC IGNEOUS ROCKS IN CRUSH ZONE
SOIL COVER
2 ARGILLACEOUS SANDSTONE
3 RED SHALE WITH FLAGGY SANDSTONE
4 OBOLELLA LIMESTONE & SHALE
5 SANDSTONE WITH REDLICHIA
6 FOSSILIFEROUS FLAGGY LIMESTONE
7 ARCHAEOCYATHINAE LIMESTONE
8 POUND QUARTZITE
9 FLAGGY SLATES & CALCAREOUS BANDS
10 CHOCOLATE SHALES
11 A.B.C QUARTZITES & SANDY SLATES
12 CHOCOLATE SLATES
13 CHOCOLATE & GREY SHALES
14 HIEROGLYPHIC LIMESTONES
15 SLATES WITH INTERRUPTED LIMESTONE HORIZONS
16 LIMESTONE WITH SLATES & SANDSTONE
17 SHALE
18 FLAGGY LIMESTONE
19 FLAGGY QUARTZITE
20 FLAGGY QUARTZITE WITH DOLOMITIC & SLATY BANDS
MT. ELKINGTON
FAULT & CRUSH ZONE
ANGORICHINA HOSTEL
ORATUNGA HS.
BLINMAN
ANGORICHINA HS.
ALPANA HS.
YOUNGERA SPRINGS
PATTERTON WATERS
GUM CK. HS.
MT. EMILY
THE BIG HILL
MT. LYELL
WIRREALPA
BENDIETA CREEK
GRINDSTONE RANGE

THE BASIC IGNEOUS ROCKS OF THE BLINMAN DOME

BY PETER F, HOWARD

Summary

The Blinman dome is comprised of middle and upper Adelaide System sediments which were faulted and crushed and subsequently intruded by basic igneous magma during post-Cambrian times. This diastrophism is discussed and petrological descriptions of the basic and related rocks submitted. Attention is drawn to the arrangements of the basic bodies and an early form of ring dykeing is suggested for the unique structure.

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[Read 9 November 1950]

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Contents

INTRODUCTION

In the vicinity of Blinman occur a great number of small-scale igneous intrusions into the middle Adelaide System, which consist of (1) an older group of basic intrusions giving rise to intraformational flows, and (2) a later period of igneous intrusions in the form of transgressive dolerite bodies.

These occurrences and the rocks considered herein occur within a radius of four miles of the centre of the Blinman dome. Other intrusions occur six miles to the N.N.W. at Wepowie, fourteen miles east on the road to Wirrealpa and twelve miles to the south at Enorama, which is at the head of the Oraparinna dome. In all cases the intrusions are in a belt of crushed sediments.

The horizons of the lower beds of the Blinman dome have been determined in relation to a known marker horizon in the system at Mt. Emily, and fall into the upper section of the slates and arenaceous series overlying the main tillite horizon. Masses of intraformational melaphyre occur within this slaty horizon, and later irregular shaped stocks intrude the system to points above this horizon.

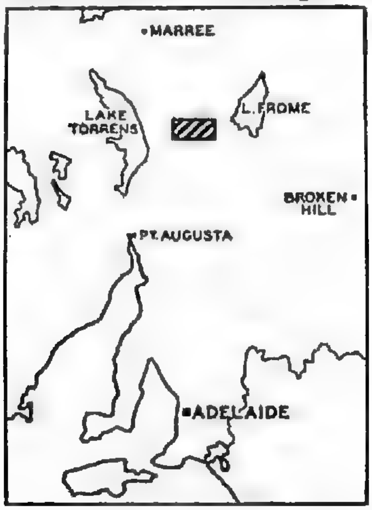
Though the region was an important copper field from 1862 until 1918, references to previous work on the central area and igneous rocks are limited to Dickinson (1942) and Howchin (1922), with subsequent petrological notes by Benson (1909). Mawson has made a special study of the sedimentary rocks of the surrounding region; see especially Mawson (1942).

NOTES ON THE ACCOMPANYING MAPS

Advantage was taken of aerial photographs kindly made available by the Department of Defence. A photo-geological map of the Parachilna-

Blinman-Wirrealpa district was drawn up from a trimetrogon set consisting of two vertical runs coupled by an oblique set covering the central portion including Parachilna gorge, Blinman and Wirrealpa.

An Arundel plot was used and the scale of the southern run adjusted to the more northerly one, the scale being approximately 1·6 inches to the mile. The geological detail was transferred from the photographs, and for the greater part checked by field work. It shows well the trend of the Adelaide System in the area, and the disturbances which can be traced right across the ranges from Parachilna to Wirrealpa. The 3 inches to the mile



Locality Plan

inset map of the centre of the larger map was compiled from oblique photographs by gridding and close ground checking, and relates an accurate picture of the topography and geological structure of the area dealt with in this paper.

The detail of the sediments inside the intruded area has not been shown as this portion of the dome is highly shattered flaggy quartzite not showing any well-defined marker horizons.

STRATIGRAPHY

The detailed sections run were limited to the east and south of Alpana homestead. The line of section submitted was considerably staggered in order to avoid crush zones and soil cover. The upper extent of the beds is the bottom of the hieroglyphic limestone horizon, and the strata recorded on the following pages follow in downward succession.

Hieroglyphic Limestone

(1) Beds of considerable but unmeasured thickness above item (2). Dip 36°.

Slates

(2) 1,400 ft. Mostly green-grey, but passing to chocolate near upper limit (average dip 27°).

Cryptozoonic Limestone

(3) 50 ft. Dip 17°.

Slate

(4) 170 ft. Dip 20°.

Calcareous Sandstone

(5) 20 ft. Dip 22°.

Slate

(6) 270 ft. Dip 23°.

Cryptozoonic Arenaceous Limestone (Mt. Emily). Total thickness 30 ft.

(7) 8 ft. Arenaceous Limestone with small limestone bands a few inches thick, which show extremely rich cryptozoonic horizons. Dip 5°.

(8) 12 ft. Impure and arenaceous flaggy limestone.

(9) 10 ft. Massive arenaceous limestone with coarse intraformational breccia.

Shale

(10) 700 ft. Grey to green shales. Dip 10°.

Arenaceous Limestone and Standstones. Total thickness 339 ft.

(11) 91 ft. Massive limestone with cryptozoonic horizons.

(12) 53 ft. Sandstone with flaggy horizons.

(13) 18 ft. Limestone commencing with a cryptozoonic horizon passing up into an intraformational breccia.

(14) 20 ft. Massive quartzite and grit.

(15) 48 ft. Flaggy limestone passing up into massive cryptozoonic limestone, flaggy arenaceous limestone.

(16) 32 ft. Calcareous grit.

(17) 9 ft. Flaggy sandstone.

(18) 8 ft. Arenaceous limestone.

(19) 31 ft. Limestone with cryptozoonic and gritty bands, including intraformational breccia.

(20) 29 ft. Quartzite becoming gritty and calcareous.

Slate

(21) 400 ft. Finely laminated graded chocolate slates. Becoming calcareous. Dip 16°.

Arenaceous Limestones and Grits. Total thickness 563 ft.

(22) 50 ft. Calcareous grits passing up into massive limestone with cryptozoonic horizons.

(23) 47 ft. Limestone, commencing with an arkosic grit becoming pelleted.

(24) 43 ft. Limestone with excellent cryptozoons in the purer bands. Ends with an intraformational breccia.

(25) 232 ft. Blue limestone with a wavy structure passing up into quartzite.

(26) 6 ft. Buff limestone.

(27) 9 ft. Arkosic grit.

(28) 111 ft. Massive limestone with good cryptozoonic horizons.

(29) 51 ft. Arkosic grit passing up into calcareous slate.

(30) 14 ft. Arkosic grit with interbedded sandstones passing up into a pelleted and cryptozoonic horizon. Pieces of angular shale occur in the intraformational breccia.

Shale

(31) 270 ft. Shale, finely laminated with occasional quartzite bands. Dip 18°.

Limestone. Total thickness 200 ft.

(32) 127 ft. Massive blue arenaceous limestone with cryptozoons.

(33) 10 ft. Flaggy sandstone.

(34) 63 ft. Arenaceous limestone, both flaggy and massive, passing up into a cryptozoonic horizon.

Flaggy Quartzites. Total thickness 358 ft.

(35) 158 ft. Yellow to green finely laminated flags with quartzite bands in the upper limits.
(36) 3 ft. Grey arenaceous limestone with wavy markings.
(37) 55 ft. Massive and flaggy quartzites. Dip 20°.
(38) 30 ft. Flaggy quartzites. Upper limit is terminated with a one foot band of blue oolitic limestone.
(39) 10 ft. Calcareous shales.
(40) 12 ft. Flaggy quartzites with a four foot oolitic limestone horizon.
(41) 38 ft. Quartzite becoming buff coloured, flaggy with ripple marks.
(42) (43) 52 ft. Quartzite ripple marked at the top.

Slate. Total thickness 874 ft.

(44) 185 ft. Flaggy slate readily splitting into large flags.
(45) 218 ft. Slate—a little arenaceous.
(46) 231 ft. Slate. Dip 34°.
(47) 240 ft. Slate, slightly calcareous at base then becoming arenaceous, occasionally showing cross-bedding.

Flaggy Slates and Limestones. Total thickness 153 ft.

(48) 10 ft. Intraformational breccia limestone.
(49) 2 ft. Flaggy quartzite.
(50) 2 ft. Flaggy limestone.
(51) 2 ft. Flaggy quartzite.
(52) 50 ft. Flaggy limestone.
(53) 28 ft. Sandy slate.
(54) 2 ft. Blue limestone.
(55) 25 ft. Calcareous slate.
(56) 7 ft. Limestone.
(57) 15 ft. Flaggy quartzite.
(58) 10 ft. Grey-blue limestone, as intraformational breccia.

Flaggy Quartzites. Total thickness 1,250 ft.

(59) 70 ft. Quartzite becoming flaggy.
(60) 550 ft. Flaggy quartzite.
(61) 420 ft. Massive quartzite.
(62) 41 ft. Flaggy sandstone.
(63) 149 ft. Sandstone with dark bands. Dip 56°.

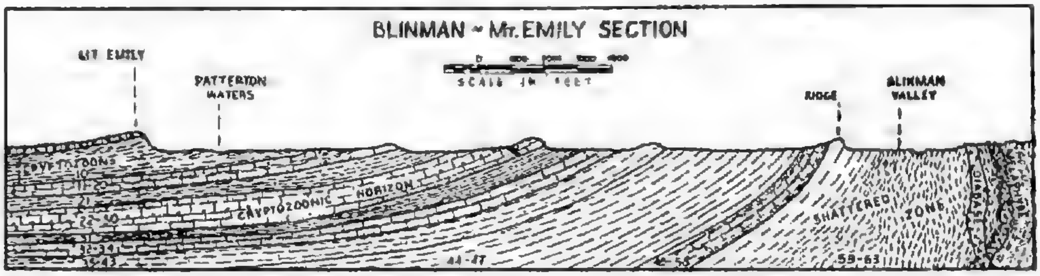
From here the thicknesses of the underlying beds are difficult to determine with any certainty, but the general sequence is slate, melaphyre, slate, dolomite, quartzite and flaggy quartzite showing ripple marks, pseudomorphs after halite and slaty bands.

There is a direct correspondence from 1 to 10 of the above section with 41–34 of Mawson's Brachina Creek Section some 30 miles to the south, and it seems likely that the quartzite ridge surrounding the dome (including Mt. Elkington) would correspond to the greywacke horizon indicated in Mawson's Structural Map of the Flinders Ranges. Taking it as such, the centre of the dome corresponds to the slate, arenaceous slates and flaggy quartzites overlying the Sturtian tillite and accompanying grits.

The variation in the thickness of the rocks in this area as compared to those at Brachina Creek area is considerable, as is seen in the thickness of the submitted section, 4,410 ft. as compared to the corresponding 3,280 ft. at Brachina Creek.

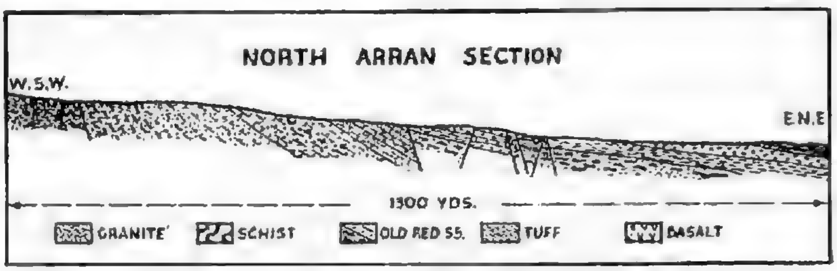
DIASTROPHISM AND ACCOMPANYING INTRUSIONS

The Blinman dome has a peculiar feature in that, ringing about its inner 20 square miles is a pronounced ridge of flaggy quartzite within which a zone of great shattering and faulting occurs. From a brief study of the accompanying map this zone is readily distinguished, as into it have been intruded the dolerites of the district. The belt is approximately one mile wide and runs parallel to the above mentioned ridge, leaving a folded central core or area less disturbed and free of intrusions.



Coupled with this it is found that the greater part of the dome, except the south-west block, shows a pronounced increase of dip in the last 800-900 yards approaching the perimeter ridge. Thus there is an increase of 50°, from 20° at the Youangera Springs horizon to 60-70° degrees at the ridge itself. In the north-east section of the dome, the effect reaches its greatest intensity where the beds are tilted from 23° up to 85° overturned. This represents an increase of over 70° in a distance of 700 yards or less.

This structure is similar to that of the island of Arran, Tyrrell (1928), where the sediments consist of an arenaceous series including the lower Old Red Sandstone, a lower group of sandstone and basic lava, tuffs, red shales and marls. These sediments are assumed to have been flat-lying Mesozoic rocks lying on Dalradain schists and post schist sediments without any angular unconformity. During the Cainzoic a great boss of granite, radius four miles, intruded the area and now forms the nucleus of North Arran. The granite intruded the ring of Dalradian schists, and where their strike was S.W. to N.E. with a dip predominantly to the S.E. it was steepened, and on the other side of the intrusion where the sediments were originally towards the granite, the uplift overturned the sediments so that they dipped away from the intrusion. This is well seen in sections across North Arran.



However, the point which is to be emphasised is that the structure of the surrounding sediments is clearly dependent on the intrusion. In general, the strike of the adjacent rocks curves in uniformity with the granite margin. Their dips are outward: steep for a distance up to a half mile before they gradually fall back to their low angle. See Section.

Comparing the Blinman area with Arran, there seems to be a direct analogy. Though the centre of the Blinman dome is not occupied by a mass of igneous rock, nevertheless it is clearly seen that to form the structure that now exists there must have been a great force from beneath to lift the sediments into their upturned position and cause a circumferential belt of shattering perforated by dolerite intrusions. It suggests the emplacement of a large basic igneous body which has been arrested while plugging a central core of sediments upward. In age the intrusion would have followed a late stage of the Cambrian to Post Cambrian folding and allied faulting. Only the more obvious faults were mapped and those few, together with others not indicated, are nearly all located along the axes of two structural bulges which are located one either side of the dome.

The possible sequence of events suggested is as follows: The tectonic forces which originally acted on the Adelaide System sediments in the Blinman region were not completely relieved by the formation of a simple domal structure and a coupled force developed giving rise to the two structural bulges mentioned. This couple set up crushing and faulting movements at the apex of the dome, while part of the stress took relief by faulting along the axes of the bulges.

The ultimate fracture of the apex of the dome allowed the periclinal sediments to be buttressed and upturned against the central core. In this way the stresses would have been finally relieved and the path prepared for the emplacement of the igneous mass from beneath. Fig 1 represents the likely cross-section of the structure.

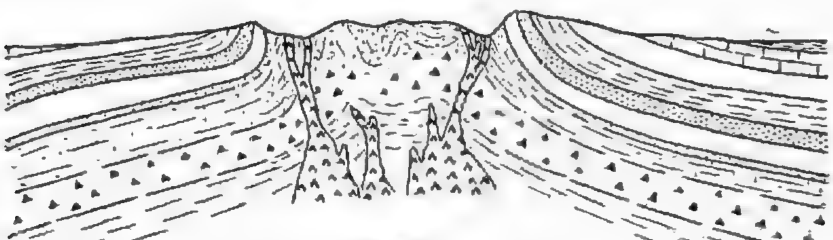


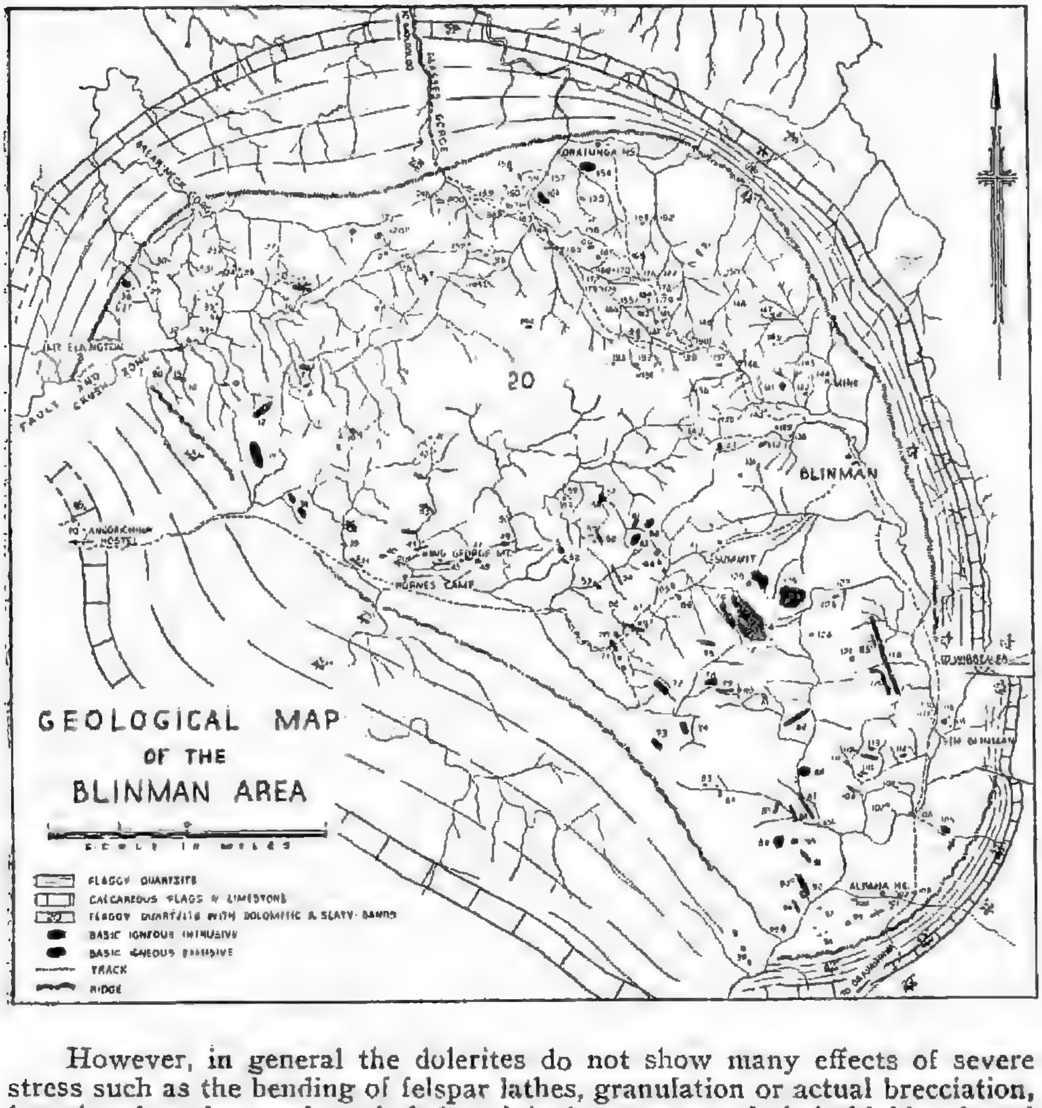
FIGURE 1.

The diastrophism causing this phenomenon and the time of the intrusion would appear to have been considerably Post-Cambrian. Support for this lies in the fact that the shattering of the dome has been at comparatively shallow depth, as indicated by the predominence of crushing and shattering over the occurrence of fold phenomena. Even the shales have tended to shatter into large blocks in a finer matrix. It is not conceivable that this condition could arise if 20,000 to 30,000 ft. of Adelaide System and Cambrian sediments were superimposed on the beds in question. Therefore there must have been a considerable period of erosion after the upheaval of these sediments in Cambrian and Post-Cambrian times before the conditions necessary for the development of the structure could arise.

To suppose that the central core was of an older age, folded, faulted and intruded before the deposition of the remainder of the Adelaide System would infer an unconformity which should be clearly evident. Moreover, this suggestion could not explain the unintruded central core.

EFFECTS OF RESIDUAL STRESS ON INTRUSIONS

The general shattering and brecciation with little folding even in the slates and shales, and the formation of the present conditions at shallow depth, would not have been accompanied by a uniform pressure over any area. On the contrary differential pinching on the sediments according to varying stresses, is the only explanation of the origin of the coarsely foliated bi-mica schists and gneisses associated with many intrusions (see p. 187). A following period of low grade stress must have persisted for a great length of time, with intermittent revivals causing brecciation of isolated dolerite bodies, as in the case of locality 96.



However, in general the dolerites do not show many effects of severe stress such as the bending of felspar lathes, granulation or actual brecciation, but the slow destruction of their original textures and their highly altered composition serve to indicate that a low grade stress insufficient to impart a new type texture was operative.

An interesting occurrence of acid rocks in the area is seen at locality 157 and 172, where there are coarse pegmatitic rocks. 157 is hypidiomorphic

granular containing a large number of accessories, and may represent a late phase of extreme differentiation of the basic magma. This is possible as such occurrences are few and their size comparatively small.

At locality 172 is a small reddish granitic gneiss, which was referred to as granite by Howchin (1922). Microscopically it is very similar to the pegmatite of locality 147, except in its gneissic structure and greater amount of biotite: it appears to be the stressed equivalent of that at 147. These two would presumably have been intruded well after the dolerite, one accompanied by a pinching and the other not, showing that the differential stresses were still operating. Post crystallization granulation of these two rocks points to repetition of stress at a still later period.

FIELD RELATIONS OF BASIC ROCKS

The melaphyres are intraformational and thus belong to a much earlier period of igneous activity than the dolerite bodies which are found intruded into the overlying younger sediments. The highest point to which the dolerites have penetrated the System and the horizon of the flows may be judged by their relative positions to the perimeter ridge, which is approximately stratigraphic. The dolerites intrude the ridge horizon at Mt. Elkington, while at South Blinman the flows are 1,000 to 1,500 ft. lower in the system. The dolerites of South Blinman are also clearly above the flows.

The earth movements causing the shattering and brecciation before and during these intrusions were responsible for the frequent faulting and cutting out of melaphyre beds, and in some cases their overturning as at 119. This bed is overturned 5° to the E.S.E. but remains parallel to the regional strike.

Though the melaphyres can be distinguished at intermittent intervals about the dome, they are scarce in the west and north, and are concentrated mainly in the S.E. This indicates that the flows were not of a regional scale but confined in extent about their source.

Occurrences at 119, 120, 112, 113, 82 and possibly 79 and 78 appear to be the same flow at different points. They consist of two parallel flows at closely separated horizons. In each case no lensing or variation of thickness could be distinguished. In these and the others, overlying ash beds, are very limited and measure only a few inches in thickness. They grade into arkoses containing actinolitic and chloritic material, to chocolate sandstones, to chocolate slates, and finally into grey and purple shales.

Sandstones are found underlying the melaphyres at 112, 82 and 79, and are current bedded. However, these do not appear to be universal, indicating the varying conditions over a small area under which the flows were laid down. Shallow water and arid conditions were common in the area as a whole, as can be judged by the underlying sediments, which consist of grey slates showing ripple works and halite pseudomorphs. These grade up into ripple marked quartzite and sandstone bearing halite pseudomorphs and lines of current bedding indicated by ilmenite grains.

As no pillow lava structure is evident, it seems likely that these deposits were caused by fissure eruption on to flat-lying lake beds, dry or nearly dry. That the mechanism of eruption was by fissure flows is supported by the small amount of ash and tuff in the area. In several areas, such as 78, 85 and 77, amygdaloidal melaphyre is actually interbedded with very thin bands of shale, sandstone and other sediments, so that there must have been either submarine or shallow water conditions. In the case of 78, the large spheroidal shapes of weathering melaphyre in situ suggests former

pillow structure, but in its weathered condition it is difficult to tell. The total thickness of basalt, its amygdaloidal counter part, and interbedded sediments, is upward of 300 ft., and is quite similar to 77.

77 is a very complex hill capped with brecciated fine grained basalt, which appears to have been intruded by later dolerite found about it in numerous small off-shoots. Proceeding N.W. from the summit amygdaloidal melaphyre is interbedded with bands of sediments which eventually pass up into purple shales. To distinguish these rocks as spilites under the microscope is quite difficult, because the stresses which have operated on the area have effected destruction of the felspar with the production of very little epidote, while the felspar or residual felspar is often albite. Thus the original compostion of the felspars need not have been very basic in composition.

At locality 71 is a fine-grained intraformational basalt clearly conformable with the underlying sandstone and this in thin section is wholly albite, chlorite and magnetite. and possibly represents a spilite. In the field no pillow structure can be detected.

This is a class of flow which is quite distinct from those seen at localities 82, 112, 72, 119 and others, where occurrences are obviously sections of one and the same flow, having the identical amygdaloidal rock resting on a chloritic sandstone. The base of this melaphyre formation there is a highly scoriaceous zone where, possibly, it contacted a cold or wet surface. This is followed by a more compact phase with lines of drawn out vesicles parallel to the base, indicating flowage. Nearer the top the scoriations become greater to an extreme degree at the surface, and are then followed by a few inches of ash, a foot or so of chloritic arkosic rock, and so on as mentioned previously. The thickness of the four outcrops is constant at approximately 140 ft. In the case of 119 and 112, and possibly 82, there are two flows, the upper one separated from a lower body of melaphyre by over 400 ft. in the case of 119, and over 300 ft. at 112, of slaty sediments which are mostly soil-covered.

Feeding pipes or vents from which these flowed were not found. It is possible that their rock type is so familiar to the fine-grained dolerite as to have passed detection. Locality 77 could bear re-examination in that light.

As the later dolerite intrusions took place into extremely shattered areas, their shapes naturally tend to be irregular. Thus the occurrence of anything but short, ill defined dykes is uncommon. The only good example of a dyke is at locality 165, where it is seen vertically disposed crossing several creeks in a N. 265° trend. This body is 40 ft. wide and has a length of approximately 200 yards. The contacts are clearly defined by white bands of decomposing fritted edges.

Less well defined bodies occur at localities 149, 69 and 68, and in all cases they are comparatively short in length as at locality 68, where the dyke is eight yards wide and thirty yards long. This outcrop stands out as a ridge three feet high and has weathered into spheroidal boulders. Localities 149 and 69 are cases where the contacts are not good but the widths of outcrop are maintained for the observed lengths of the bodies, 50 ft. and 120 ft. respectively.

However, the shape and specific form of most intrusions are nondescript. They occur either as slightly elongated bodies, lenticular in shape, or more commonly as sub-circular bodies with brecciated sediments drawn round them by the uplift of the intrusion. Creeks transecting such lenticular or sub-circular bodies give, at times, the impression of a dyke. The majority

of the outcrops referred to as dykes by Howchin (1922) are thought to be slightly elongated dolerite plugs. In some instances lines of weakness are intruded by a number of such bodies separated by intermittent zones of brecciated sediments. Examples of this are seen at localities 64, 65, 66 and 96. In the former case 64 and 66 are concordent with unbrecciated sediments and thus approximate to a sill structure.

A similar type of body is seen to the south at Enorama. Here many of the bodies are semi-concordant injections elongated parallel to the general strike of the sediments in the surrounding area. The largest of these lenticular plugs is approximately one mile long and 700 ft. across at the widest point. Smaller bodies are joined by subsidiary dykes and stringers, so that what appear as a series of distinctly unconnected intrusions on the surface are probably a single concordant intrusion at no great depth.

MINERALOGY

The Blinman dolerites are composed of basic plagioclose, sub-calcic augite, pigeonite, plus or minus olivine. Magnetite, ilmenite and apatite are primary accessories. Late dueteric minerals comprise quartz, albite, while anorthoclose may be present in some instances, but its presence is difficult to distinguish under the ordinary microscope due to its small size. Because of the universal alteration of the minerals by saussuritization and uralitization, details of minerals become more descriptive in nature than specific optical data.

Plagioclase

This mineral is marked by brown dusty inclusions which are found in nearly all the older basic rocks of South Australia, including the Musgrave Ranges, the Barossian Complex of the Mt. Lofty Ranges, and in certain of the intrusions of the Flinders Ranges.

These inclusions become particularly dense in some instances, and resemble near-basal sections of biotite. Such inclusions are described in rocks collected by Wilson (1948) from the Musgrave Ranges. In all these cases inclusions are expelled immediately recrystallization commences, and thus it is a useful guide in determining whether or not a plagioclase has suffered recrystallization, or to what degree, as judged by the clear peripheral zone about the dusty brown core. In cases such as the labradorite of the somewhat metamorphosed basic igneous rocks of Woodside (Mt. Lofty Ranges), which is quite clear, it would be inferred that though it may still have a composition close to its original one, it has, nevertheless, been regenerated.

Saussuritization with concommittant regeneration of plagioclase to a more acid variety is so common that there is little chance of determining how basic the composition originally was. Rock (9016) illustrates the least affected pagioclase found in the area. This has a maximum basic composition of $Ab_{15}An_{85}$, which is only mid-labradorite. Zoning is obliterated at an early stage. Rock (9016) is one of the only examples where zoning is retained. In it successive zones in the plagioclase lathes range from $Ab_{36}An_{64}$ to $An_{60}An_{40}$.

The predominant composition is acid andesine to oligoclase, the latter being untwinned and of low relief, approximately equal to balsam.

The average size of the lathes is 1·3 mm. × 0·4 mm., and up to 7 mm. × 1 mm., in the gabbroic types.

Saussuritization has given rise to great quantities of epidote, clinozoisite and zoisite with a little scapolite in a limited number of sections. Calcite is in some cases quite prominent. White micaceous matter is occluded within the plagioclases and appears to have formed during the same process

which gave rise to the epidotes. Although usually colourless it is sometimes seen in shades of light green. E. B. Bailey and G. W. Grabham, in their paper "Albitization of Basic Plagioclase Felspars" suggest that this mica results from a late deuteric introduction. However, it would be more logical to assume that it is a soda mica such as paragonite, which has come from the plagioclase enclosing it. In so many cases it is the chief alteration product and forms in such a manner as to cast little doubt as to its secondary origin. In altered lathes it is found either parallel to the basal cleavage or to the "c" axis, that is, the length of elongation. These phenomena are best seen in the slides of rocks 9017, 9034 and 2823.

The *epidote* usually forms in much larger grains than does the zoisite and, at times, it is strongly pleochoic in yellow-greens. Cleavage may or may not be evident as in the epidote of rock (9015), where it occurs as remarkably large anhedral to subhedral crystals free of cleavage and fractures. Biaxial (— ve) with a large optic axial angle of 80°.

Zoisite always forms in rather small grains which are not large enough to yield optical figures. Odd grains are biaxial (+ ve) with a low 2V in vicinity of 40°. It is most readily distinguished from the epidote by its lack of pleochroism and its lower birefringence often showing anomalous effects.

Clinozoisite is common, and it is possible that, as it also shows a low birefringence and anomalous blues like zoisite it may accur more frequently than supposed. In sufficiently large grains it is readily distinguished by its biaxial + ve figure, $2V = 80°$. In the case or rock 9020, a phenocryst of felspar has been completely replaced by clinozoisite.

PYROXENES

Augite—This is not common, but where it occurs has a 2V (+ ve) of 45-60°. An accurate range of $Z \Delta c$ cannot be determined without the use of the universal stage, but it is probably about 39°. The size is as with the other pyroxenes from 1·9 mm. × 0·50 mm. to an average of 0·90 mm. × 0·40 mm.

Sub-calcic augite is the predominant pyroxene and is taken as ranging from 2V 35/45 degrees, $Z \Delta c$ 37/41 degrees. Twinning is not common, and at times a faint pleocoism is evidenced. X = faint fawn, Y = faint pink, Z = yellowish fawn. The crystals are subhedral to anhedral, occurring intersertally between the interlocking plagioclase lathes, or giving ophitic textures when crystallizing after the plagioclase. Generally the ophitic textures are poorly developed.

Grain sizes are above average, 0·9 mm. × 0·4 mm. The ophitic host crystal in a slide of (9033) is 8 mm. in diameter.

Pigeonites—There is little obvious distinction between these and the more calcic varieties, except for their optic axial angles, which fall into a range between 12 and 35 degrees.

Uralization in its earliest stage is seen in the slide of (9016), commencing at the edges of the pyroxene as a green coating giving a marked change in birefringence from middle second order down to first order greys and yellows. Prismatic form showing 120° cleavage makes an early appearance, but in general the alteration is from the predominantly elongated pyroxene lathes parallel to "c" axis, and the resulting amphibole is consequently also in lathes, needles and fibrous felted masses of elongated habit. Concommitant with this is the release of brown-green biotite in odd fragments. In other cases, such as in rocks 907 and 9034, there has been a very abundant release of magnetite into small grains aligned in well defined parallel lines, representing cleavage or partings. The most common amphi-

bole resulting from the uralitization has a moderate optic angle which ranges down to 40° and below, and up to approximately 60°, orresponding to hornblende. Actinolite also occurs, having a higher optic axial angle of 70/90 degrees. The maximum extinctions, though varying from 12/23 degrees, are almost constant at 15/16 degrees.

The colours vary according to the composition. The most common is a light coloured mineral which is only faintly pleochoic: X = near colourless, Y = light brown-green, Z = light green. Through gradations of deepening colours some varieties are found to be distinctly blue as in rocks 9020 and 2823, where X = light green to colourless, Y = blue green, Z = blue, and $2V = 40°$. The $Z \Delta c$ seems to be much the same as the more common hornblende, *i.e.*, approximately 15°. Alterations of this type have been met with in Canada, New Zealand and elsewhere, and will be mentioned later under the heading of petrology.

It is common in some places to find destructive weathering of the dolerites as with rock 9012, and in such instances the most common minerals formed are chlorite and calcite. Light green hornblende may be found in needle-like form intergrown with chlorite and calcite. Distinction between the amphibole and chlorite is determined by the signs of elongation, the two being opposite. This is very useful, at times they appear to be the one and same mineral.

Olivine

Pseudomorphs after olivine are found in a considerable proportion of the rocks, but in no case is olivine itself found. The pseudomorphs are mostly magnetite together with antigorite or talc. The magnetite, in many cases, preserves the original idiomorphic outlines and indicates the irregular cracks and fissures common to olivine.

Minor Constituents

Under this heading may be referred the granophyric intergrowths and accessory minerals. The introduction of quartz-albite as interstitial intergrowths is of late magmatic origin, and will be referred to under the petrology.

Magnetite and ilmenite are the two main minerals to be mentioned here. The exact proportion of primary magnetite cannot be determined at all because of the release of large amounts during uralitization. The ilmenite, though not distinguishable from the magnetite when fresh, readily shows once alteration to leucoxene occurs. This takes place in several ways. Firstly as a peripheral ring, and secondly as complete alteration, giving rise to disseminated grains and stringers of leucoxene. On recrystallization these give rise to larger grains, and might be better called sphene. The third mode of alteration is seen in the large ilmenite grains, and takes place along definite parallel planes, possibly corresponding to crystallographic symmetry.

Pyrite is seen in many of the hand specimens, and sometimes figures quite prominently.

Apatite is quite abundant in some rocks, but on the whole is not common. It is found in small rods and prisms in the rocks which have suffered most deuteric introductions.

A host of secondary minerals such as zoisite, clinozoisite, epidote, sericite, talc, chlorite, antigorite limonite, iddingsite, scapolite and albite occur, but have been mentioned in connection with the minerals from which they arose.

The mineralogy of the melaphyres bears a separate mention as they are of a different age and differ in many of their properties.

PLAGIOCLASE

Here no cases of dusty brown inclusions have been found, and whether they ever occurred cannot be determined. The plagioclase has been in all cases regenerated to acid andesine and lower, and only one instance of labradorite can be found. The determinations of the R.I. in relation to balsam is particularly difficult, as decomposition products crowd the edges sufficiently to confuse the true nature of Becke's bright line. The method using the intersection of the basal cleavage against the twin planes is not possible as regeneration has obliterated such evidence. As the extinction angles of the twin planes in the symmetrical zones rarely exceed 16° it is possible that the plagioclase could be albite. On the other hand, twinning is strongly developed, and seems too regular and coarse for an albite composition. Baveno twinning is strongly developed in places.

Unlike the dolerites, comparatively little epidote occurs, and instead the predominant secondary mineral is clear white flecks of mica orientated parallel to the twin planes. Where epidote occurs it is usually recrystallized into larger pleochroic crystals.

Pyroxenes are completely lacking and amphibole is not abundant, quite often being replaced by chlorite. Generally speaking the melaphyres are a felspar-rich and ferromagnesian-poor rock.

Olivine again occurs only as pseudomorphic magnetite, chlorite, antigorite and limonite, but is more clearly distinguished as residual olivine than in the case of the dolerites.

MINOR CONSTITUENTS that were not contained in the dolerites include rutile, haematite and anorthoclase. The latter is found in rock 2829 from South Blinman and is a late deuteric introduction.

Associations are muscovite, cholirte and quartz. More usually the introductions are of albite and not anothoclase. *Rutile* only forms in small grains, too small to show cleavage, but its red-brown colour and adamantine lustre in reflective light readily distinguish it.

Haematite is common as micaceous linings in amygdales. Where basal sections occur its red nature is discernible, otherwise it appears quite similar to the magnetite. It is also very common, filling joint fissures with regular patterns.

PETROLOGY

During crystallization there has been normal soda enrichment in the plagioclases and calcium enrichment in the pyroxenes. However, as most specimens have been considerably altered very little detailed observation in this direction could be attempted.

The order varies in specific instances, but in general the first mineral to crystallize was olivine, followed by the pyroxene with slight overlapping of the plagioclase as evidenced by the tendency towards sub-ophitic texture of felspar lathes imbedded in pyroxene. In rock (9033) there is the only instance of true ophitic texture where the plagioclase has crystallized and later has had the pyroxene crystallized about it.

The crystallization of sub-calcic augite appears to precede the pigeonite, which in all cases occurs as small residual crystals in the finer mass of the rock.

The course of crystallization of the minor constituents is obscured by alteration and late deuteric introductions, which include (1) replacement effect of albitic solutions on original plagioclases, (2) introduction of quartz

or quartz-albite and anorthoclase on rarer occasions, (3) introduction or reintroduction of chlorite, biotite, and actinolite in vesicles of the melaphyres.

One important change, commencing in the late magmatic stage, is the alteration of the pyroxene to amphibole. Though the majority of the cases give rise to hornblende or actinolite, some show variation in the blue variety with 2V (+ve) of 35 to 40 degrees. This low 2V, if it is so, could be explained by the introduction of a sodic glaucophane or riebeckite molecule or by the absorption of the sodic element of secondary albite as in the case of rock (2823), where the amount of plagioclase remaining after the breakdown in calcite, epidote and sericite is negligible. Such low 2V amphiboles are not uncommon, and have been mentioned by Winchell from New Zealand, and again by Hutton (also in New Zealand rocks). Bateman, in his article on "Gold Deposits of Urchi Goldfields," mentions occurrences of sodic amphibole as possibly due to hydrothermal introduction of sodic molecules.

CHEMICAL ANALYSIS

Rock (9010) from locality 183 was chemically analysed with the following result.

SiO_2	48·11 per cent.
Al_2O_3	15·08 " "
Fe_2O_3	4·73 " "
FeO	8·37 " "
MgO	5·87 " "
CaO	9·75 " "
Na_2O	3·33 " "
K_2O	1·45 " "
H_2O+	0·72 " "
H_2O-	0·17 " "
CO_2	0·44 " "
TiO_2	2·10 " "
S	0·19 " "
MnO	0·12 " "
	100·43

NORM

Orthoclase	8·34 per cent.
Albite	27·77 " "
Anorthite	21·46 " "
Nepheline	0·28 " "
Diopside	20·55 " "
Olivine	9·21 " "
Calcite	1·00 " "
Magnetite	6·73 " "
Ilmenite	3·95 " "
Pyrites	0·36 " "
Water	0·89 " "
	100·54

PETROGRAPHY

As pointed out, the Blinman melaphyres and dolerite intrusions have suffered a long period of intermittent low grade stress. This stress varied sharply from point to point due to the nature of the shattering, and consequently some dolerite bodies suffered little stress at all, as in the case of rock (9016), while others, as rock (9034), suffered a considerable amount; that is, greatly altered by saussuritization and uralitization. Between these two extremes there is every gradation. Though not strictly accurate, a normal classificaion is followed, based on the presence of pseudomorphs after olivine and the residual textures.

Doleritic Gabbros

Few in number and show little variation: 9017, 9034, 2823.

Dolerites

A *Olivine free*

(1) Ophitic texture: 9033, 9015, 9036.
(2) Sub-ophitic to intersertal: 9016, 9020, 9021, 9028.
(3) Relic textures: B301, B59, 9029, 9012.

B *Olivine bearing*

(1) Ophitic texture: 2830, B135, 9011.
(2) Sub-ophitic to intersertal textures; 2832, 9013.

Melaphyres

C *Amygdaloidal*

(1) Olivine free: 9018, 9014, 9026, 9031.
(2) Olivine bearing: 9027, 9024, 9022.

D Fine grained non-amygdaloidal: 9023, 9025, 9030, 9035, 9032.

Doleritic Gabbros

These coarse grained rocks are not common in the area and are confined to localities 202 and 38. Of these, locality 38 is the only large mass, and may represent the upper extention of a larger underlying mass.

Rock (9017) of locality 202 is a remarkable, coarse grained, whitish-grey, gabbroic rock with specific gravity 2·894. In thin section the rock is holocrystalline, hypidiomorphic tabular with a conspicuous granophyric intergrowth between the interlocking crystals. The grain size is average at 3·8 mm. × 1·0 mm., but individual lathes reach lengths of 8·0 mm.

Plagioclase with a modal figure of 56% is in tabular form and is highly altered so that multiple twinning is now indicated only by micaceous decomposition products along the former twin planes. The alteration products are sericite, zoisite, epidote and scapolite. The latter occurs as disseminated flakes showing cleavage and straight extinction, and therefore difficult to distinguish from sericite. However, sections without cleavage are more easily determinable, giving uniaxial (—ve) figures. The epidote is pleochroic in yellow-greens and has a distinctly higher birefringence and occuring in larger masses than the zoisite, in which the lower order colours are marked by anomalous blues. Where residual twinning is seen in the felspar, it has extinctions up to 15°, with R.I. less than that of the Canada balsam. It is best seen in peripheral zones with twin planes far apart, where it is biaxial (+ve) with 2V = 70°, and thus is Albite.

The uralite, which has a modal occurrence of 37%, has resulted from the breakdown of the original pyroxene and some residual properties such as twinning still remain. Uralitization has given abundant release of magnetite along parallel planes of the pyroxene, and these may represent original extra partings as seen in diallage or an exaggeration of the schiller structure as seen in bronzite. The alteration does not appear complete, but 120° cleavage, with extinctions of 16°, are to be observed. The interference figure is biaxial (—ve) with a moderate 2V. Pleochroism is weak in shades of green when the replacement is complete, otherwise it is near to colourless, and poikilitically includes magnetite and epidote. The light colouring would seem to be partly due to the expulsion of the abundant iron during the uralitization.

Magnetite (apart from that contained in the ferromagnesian constituent) has a modal figure of 3·1%, of which a fair proportion would be primary. Grains show octahedral and rhomb form, and include crystals of clear non-pleochroic epidote and brown rutile. Chlorite and limonite are accessory.

Granophyric intergrowths occupy the junction region of large crystals and are of late formation. The modal occurrence is 4·1%, of which quartz is 2·2% and felspar 1·9%. The growth is of albite in a quartz base, the albite showing multiple twinning with extinctions of 12°.

Rock (9034) from locality 38 varies from the previous rock in degree of alteration. Complete saussuritization, sericitization and regeneration of the

plagioclase have obliterated all signs of twinning. Residual felspar is untwinned albite-oligoclase: biaxial (+ ve), 2V = 70°. The Uralitic amphibole is colourless to X = light brown, Y = green, Z = blue-green. Ilmenite is in skeletal forms in the process of break down to leucoxene. Individual crystals of epidote are larger than those of the zoisite. Biotite and rutile occur.

Rock (2823) was collected by Howchin and labelled "Dyke West of gneiss, 1 mile West of Blinman". This corresponds to locality 140 on the accompanying map. Microscopically, this is similar to the foregoing specimens, except the original twinning is indicated only by the parallel orientation of the mica with respect to the old twinning planes. The Uralite has pleochroism such that X = light brown, Y = deep green, Z = blue. The optic axial angle is (—ve) 2V = 40°. Alteration of the hornblende has yielded chlorite and epidote. Secondary magnetite has suffered hydration to limonite. The granophyric intergrowth is prominent.

Dolerites

A1—Olivine-free zolerites

Rock (9033) is a grey porphyritic variety in which the pyroxene may be distinguished, set in a medium grained base. It is from locality 86.

In thin section this has an ophitic texture with the felspar laths set in phenocrysts of pyroxene. The larger pyroxenes are glomerophenocrysts of commonly orientated crystals which have altered along cleavage planes and lines at 90° to them. Composition varies from pigeonite (+ ve) 2V = 25/35 degrees to sub-calcic augite (+ ve) 35/45 degrees. The plagioclase is represented by a typical saussurite mass containing untwinned acid plagioclase. The uralite occurs in fibrous and acicular aggregates; X = light brown, Y = green, Z = blue, Z Δ c 12°. It is usually intergrown with light green non-pleochroic chlorite.

Accessories include odd grains of calcite, deuteric quartz, apatite, pleochroic biotite (X = light brown, Y = Z = strong brown), secondary magnetite and primary ilmenite in skeletal grains giving rise to leucoxeme.

Rock (9015) from locality 174. Microscopically the rock is holocrystalline with an ophitic texture. The plagioclase is strongly coloured by brown inclusions, which are expelled in the peripheral zones where regeneration of the mineral has been effected. Zoning shows from $Ab_{45}An_{55}$, labradorite to $Ab_{55}An_{45}$, andesine.

The uralite is light coloured and similar to the previous rock. Deeper colours occur in patches within the lighter variety, which has a somewhat higher Z Δ c of 18°. Again the optic angle appears to be somewhat lower than normal hornblende.

Sub-calcic augite is mostly broken down into uralite. Optic axial angle varies from (+ ve) 2V = 32° to (+ ve) 2V = 45°, Z Δ c = 38°.

Epidote, (—ve) 2V = 80° and lower, is non-pleochroic and shows cleavage where elongated. Illmenite breaking down into sub-translucent mass due to hydration. Magnetite is present.

Rock (9036) is a medium grained dark grey specimen in which a fair amount of green epidote may be detected. At South Blinman it is common to find green flakes and needles filling joints and veins, and has apparently originated by the removal of secondary epidote from the breakdown of the calcic felspar.

In thin section it is holocrystalline with an ophitic texture, and is traversed by an epidote vein. The plagioclase, which is $Ab_{65}An_{35}$, andesine, shows little sign of brown inclusions. The extreme phase yields glassy clear

plagioclase, R.I. < b; albite-oligoclase. The uralite is twinned. Z Δ c 25° and the optic axial angle (— ve) 75°. A different variety occurs in the vein as slender laths resembling biotite and chlorite with a maximum extinction of 16°. Chlorite is present. Epidote is both colourless and pleochroic. Accessories also include skeletal grains of ilmenite, and sphene has resulted from the recrystallization of the leucoxeme.

A2—Subophitic to intersertal dolerites

No. (9016), from locality 180, is a dark grey, compact, medium-grained rock containing clear laths of fine felspar with multiple twinning and a black ferromagnesian.

The plagioclase is elongated laths which are clear but for the brown-pink inclusions. Zoning is such that the more calcic core has a maximum extinction of 36° ($Ab_{35}Ab_{65}$), labradorite. Biaxial (+ ve) 2V = 80°, while the outer portions of the same crystals indicate andesine ($Ab_{60}An_{40}$). The probable average composition of these would be $Ab_{45}An_{55}$. Twinning is on two laws, albite and pericline with combined albite and pericline.

The pyroxene is a faintly pleochroic sub-calcic augite, X = faint fawn, Y = pink fawn, Z = yellow fawn. The lowest optic axial angle recorded was (+ ve) 37° at the rim and a maximum on the same crystal of (+ ve) 43°. Simple twinning on the 010 is present, and a slight tendency towards plumose structure is noticed. This is the only pyroxene present. Associated with the pyroxene, as a product of uralitization, is amphiboles both in the fibrous form and in prism sections showing 120° cleavage: pleochroism X = pale brown, Y = green, Z = blue-green: optic axial figure (— ve) 80°: Z Δ c 16°. Biotite is associated and is also strongly pleochroic from bright golden brown to lighter shades.

The late deuteric (?) introductions include apatite as well as quartz. Clear felspar ringing the more calcic variety is albite which has resulted from regeneration of original plagioclase.

No. (9020) is a porphyritic dolerite from locality 147. In thin section the former phenocrysts of plagioclase have been completely altered to clinozoisite with a little mica. Sub-calcic augite also occurs in the phenocrystic state.

The plagioclase has deep red-brown dusty inclusions, and does not appear unlike basal sections of biotite. Composition is $Ab_{50}An_{50}$, indicating andesine-labradorite. Where the laths have been included in the pyroxene, subsequent uralitization has been strongest at the edges, and thus the plagioclase has its edges ringed by strongly pleochroic amphibole. Clinozoisite is elongated parallel to the "b" axis and shows one strong cleavage parallel to the 001. Extinctions from 0/5 degrees. Optic axial angle (+ ve) 2V = 65.

The pyroxene occurs in two varieties, both of which faint pinkish fawn to colourless. The sub-calcic variety shows common orientation parallel to the 010, devoid of cleavage. 2V varies from (+ ve) 32° to 45°. Values up to 55° indicate augite. The common light green uralite occurs in fibrous small lath aggregates. In it strong blue patches occur: X = light green, Y = olive green, Z = blue. Odd extinction angles in it are considerably less than 16°. Deuteric quartz is present.

No. (9021), from locality 141, contains pink to flesh-red felspar and ferromagnesian minerals together with abundant iron ore. In thin section the rock has an intersertal texture with occasional structureless patches. The plagioclase is regenerated andesine ($Ab_{60}An_{40}$), which shows bent laths due to stress.

The uralite is hornblende; biaxial (— ve) 2V = 60°; maximum extinction 30°. Pleochoism: X = light brown, Y = greenish, Z = bluish. Chlorite

and magnetite are associated. Hydration of the magnetite gives rise to brown limonite. Accessories include ilmenite, leucoxene, strongly pleochroic biotite and sericite. Apatite is very abundant as needles and stubby prisms.

The late deuteric (?) alterations and introductions are much more pronounced in this section. Quartz is present as interstitial grains but has also affected an intergrowth with untwinned felspar on the edges of the plagioclase laths, thus resembling myrmekite.

No. (9028) from locality 62. Microscopically it is holocrystalline with an altered intersertal texture. The plagioclase has suffered regeneration to andesine ($Ab_{65}An_{35}$). Further regeneration has resulted in glass clear acid types together with mica epidote and chlorite.

The uralite is intergrown with chlorite. Associated biotite is strongly pleochroic: X = light brown, Y = Z = olive green. Very fine skeletal grains of ilmenite remain, together with much secondary magnetite.

Saussurite is very abundant. Epidote is in the larger crystals, being biaxial (—ve) 2V = 80°, strongly pleochroic, elongated parallel to cleavage. Its birefringence is second order with some anomalous colours, which make it very similar to clinozoisite, which is biaxial (+ ve) 2V = 80°.

A3—Dolerites with relic textures

No. B301 is a dark grey rock from locality 96, where the outcrop is brecciated in a crush zone. Phyllitic contact rock is veined with green fibrous chrysotile.

In thin section the original texture has been entirely obliterated, giving rise to a structureless mass of secondary minerals. The plagioclase is oligolase. The uralite is light coloured: X = pale brown, Y = pale green, and Z = pale teal-blue; it is very abundant as fibrous, flaky and lath-like aggregates having oblique extinctions up to 15°, and intergrown with pale green, antigorite and chlorite. The antigorite has very low birefringence, straight extinction and opposite sign of elongation to the chlorite. Anomalous blue chlorite is found in several veins crossing the section. Pleochroic epidote is abundant and pale brown to green pleochroic biotite is also present. Ilmenite as skeletal crystals has given rise to translucent leucoxene.

B59, from locality 139, has a relic ophitic texture. The plagioclase has been completely regenerated to low R.I. glassy albite-oligoclase, though some andesine is still present in the sericite-zoisite-epidote pseudomorphs after original calcic plagioclase.

The uralite is typical hornblende, and associated with it is fibrous, radiating, length-slow antigorite. A little pyroxene still survives as colourless anhedral fragments bordered by zones of uralite. It is biaxial (+ ve), 2V moderate, $Z \Delta c$ 40°: augite.

The accessories are secondary except for ilmenite, which occurs in skeletal grains. Zoisite in fine aggregates shows anomalous blues as distinct from the epidote with higher colours and biaxial (—ve), 2V = 80°. Secondary magnetite has resulted from the uralitization.

No. (9029), from locality 63, has a texture which is interlocking in nature. The original plagioclase twinning is indicated by alteration along parallel lines, corresponding to former twin planes. The alteration products assume large sizes and specific properties may be determined.

The uralite has an optic axial angle of (—ve) 80°. However, the bluer sections appear to be very much lower than the angle set for normal hornblende (52°). Magnetite and biotite are associated. Frayed fragments of augite have optical axial angle of (+ ve) 2V = 40°. Pigeonite, 2V = 25/35 degrees, is present.

Epidote and zoisite occur together, as already recorded. No leucoxene is evident, and therefore the skeletal sub-translucent grains are taken to be

hydrated magnetite. Limonite occurs as dense red-brown amorphous material.

No. (9012) occurs at locality 137, where the dolerite is finely jointed into flags about three inches wide. From these joints destructive weathering of the dolerite has taken place, giving yellow-green bands either side of a normal dark grey medium-grained rock.

In thin section this holocrystalline rock is almost structureless. The felspar is andesine ($Ab_{60}An_{40}$). The uralite is complex, due to destructive weathering following uralitization. The amphibole is light coloured, shows simple twinning and occurs mostly in needle-like aggregates: X = light green-brown, Y = Z = light green; Z Δ c 16°. The optic axial angle is (— ve) 50°. This amphibole is intergrown with calcite and chlorite, the latter exhibiting low birefringence and often anomalous blues.

Epidote is strongly pleochroic and has been recrystallized and segregated from the original saussurite. The iron ore is titaniferous and has been broken up into microcrystalline masses which grade into granules of sphene.

Olivine-bearing dolerites

B1—Ophitic olivine-bearing dolerites

No. (2830), collected by Howchin and described by Benson. This is labelled "west side of Blinman mine," which probably corresponds to locality 142.

In thin section it is holocrystalline with an ophitic and porphyritic tendency. Pyroxene is abundant as colourless anhedral phenocrysts with peripheral uralite: it is sub-calcic with an optic axial angle of (+ ve) 36/44 degrees, and has a maximum extinction of 44°.

The plagioclase has been completely altered to a colourless micaceous mineral, and no regenerated plagioclase can be identified. A little epidote is evident.

The olivine occurs as antigorite and talc (?) pseudomorphs, with the production of abundant secondary magnetite, which outlines the former idiomorphic form.

Rock (B135), from locality 201, is a dark grey medium-grained rock containing blotchy patches of ferromagnesian minerals.

The rock has residual ophitic texture with plagioclase laths in process of alteration interlocking within larger pyroxene crystals. The pyroxene is colourless pigeonite, with an optic axial angle as low as (+ ve) 20°. Higher values carrying it into the sub-calcic augite zone (Z Δ c 35°).

The uralite is an amphibole which shows pale green colours and weak pleochoism, but in many places the colour and pleochroism become marked: X = light brown, Y = green blue, Z = blue. Here the source of the blue amphibole seems to be late deuteric introductions along a fissure, for in the immediate vicinity of the latter the pronounced blue colour appears. Possible pseudomorphs after olivine are comprised of felted masses of light green chlorite and antigorite associated with magnetite, which forms irregular lines corresponding to original fractures.

The plagioclase is altered to a dense microgranular aggregate of zoisite, epidote and sericite—epidote is often removed and recrystallized into large pleochroic grains. The residual plagioclase is of low R.I. $<$ balsam, and shows occasional twin lamellae: composition, albite-oligoclase. Ilmenite forms skeletal crystals with pronounced lines along which leucoxene has formed, and it could be that these represent octahedral cleavage, along which the alteration to leucoxene has been initiated. Sphene and magnetite are accessory.

No. (9011) is a dark grey medium-grained rock containing laths of fine felspar and black ferromagnesians. Found at locality 137. The felspar, where still fresh, shows dusty brown inclusions as in (9016) and is labradorite ($Ab_{50}An_{50}$). Clinozoisite occurs in laths yielding biaxial (+ ve) figures 2V = 70°. Uralite is often porphyritically included in the felspar, and though usually light green more highly patches occur: X = light yellow-brown, Y = olive green, Z = blue. Maximum extinction is 23°. Optic axial angle is (— ve) moderate. Light green laths of chlorie and apatite are often associated with the introduced deuteric quartz.

Pseudomorphs after olivine consist of magnetite and antigorite. Pyroxene is subordinate, and is seen only as anhedral residual laths that have escaped uralitization.

No. (2832) is a specimen collected by Howchin and later described by Benson. Labelled "the dyke near the gorge, on the old road five miles west of Blinman". Exact locality uncertain.

Microscopically the rock is porphyritic with a sub-ophitic texture. The phenocrysts are sub-calcic augite, biaxial (+ ve) 38/44 degrees, with maximum observed extinction of 35°. Phenocrysts of olivine are completely altered to aggregates of magnetite, antigorite and higher birefringent talc. The plagioclase is secondary andesine ($Ab_{55}An_{45}$).

Melaphyres

C1—Amygdoloidal olivine-free melaphyre

No. (9031). This is a dark grey porphyritic vesicular rock from locality 77 containing phenocrysts of light brown felspar and light green chloritic masses set in a dark fine grained groundmass. Vesicles are filled with deep brown siderite associated with a little limonite. Other vesicles contain calcite and quartz. Common features are the lining of vesciles and micaceous haematite, the occurence of green copper stains and odd grains of pyrite.

In thin section the rock is holocrystalline porphyritic and highly vesicular. The phenocrysts are set in a devitrified groundmass. The plagioclase gives extinctions up to 29° in the symmetrical zone, indicating labradorite $Ab_{60}An_{40}$). However, the majority has maximum extinction of 16°. The R.I. in relation to balsam is difficult to determine due to the interference of alteration products and the obliteration of the basal cleavage. But as good and well defined multiple twinning is present the composition is assumed to be $Ab_{55}An_{45}$: andesine.

The only ferromagnesian is light green chlorite occurring in large isotropic basal sections. Siderite is abundant as pleochroic brown to lighter shade. Limonite is associated and is quite common as a coating over the siderite. Calcite is intersertal with the groundmass, but is difficult to distinguish from siderite as the former grades into siderite by simple iron replacement.

The groundmass is fine grained with an intersertal texture which does not show any flow structure. The above minerals are represented in addition to abundant magnetite, haematite and rutile. The late deuteric introductions are uniaxial (+ ve) glass clear quartz, and low relief biaxial (— ve), 2V = 43° anorthoclase, together with minor muscovite and chlorite, which are probably a recrystallization of the alteration products.

The amygdales are all filled with calcite or pleochroic siderite and associated red-brown limonite, quartz, felspar and chlorite showing regular zoning. Successive zones commence with magnetite of the groundmass to a light green isotropic chlorite zone, followed by a haematite-chlorite zone in which the chlorite is intersertal between the flaky haematite, which in basal sections

is translucent red. This is followed by an intergranular mass of potash felspar and quartz before the final residual cavity is filled by siderite.

No. (9026), from locality 92, is a pronounced variation. A fine grained amygdaloidal containing a series of long drawn vesicles lined with dark green silicate and calcite.

In thin section the texture has an intersertal form with glomerophenocrysts of felspar alteration products. The former felspar phenocrysts have been saussuritized, resulting in a fine mass of clear untwinned albite intergrown with chlorite. The mass does not show epidote, which has been recrystallized and removed to the general groundmass. The latter shows saussuritized plagioclase as frayed fragments with very little multiple twinning. Unlike the phenocrysts, plagioclase here includes epidote. Ilmenite is partially altered to leucoxene. Vesicles are elongated and vein-like, lined with thick green mattered chlorite in non-pleochroic isotropic sections, inside which is quartz, calcite, and haematite with disseminated laths of green chlorite.

No. (9014) is a light grey porphyritic rock containing stumpy pink plagioclase phenocrysts set in a fine groundmass containing little dark mineral content.

In thin section the felspar has prominent Braveno and albite twinning; R.I. greater than balsam; biaxial (+ve), $2V = 85°$, indicating andesine. Regeneration of a higher order has given glassy clear varieties of oligoclase. The groundmass oligoclase with original ferromagnesian represented by green chlorite and biotite. Interstitial cavities and vesicles are filled with calcite and micaceous haematite, which is readily detected by its red basal sections. The late dueteric introduction is quartz and possibly oligoclase associated with which is accessory apatite.

C2—Olivine-bearing amygdaloidal melaphyres

No. (9027), from locality 94, is a light green amygdaloidal specimen containing plagioclase phenocrysts and dark green silicate in a finer mass

In thin section felspar and olivine are observed as phenocrysts, the former is by far the most abundant mineral. In general composition the felspar is andesine ($Ab_{60}An_{40}$).

Olivine forms euhedral phenocrysts which have suffered breakdown into magnetite and a mass of light green low birefringent antigorite. Red amorphous haematite or limonite represent former iddingsite. Uralite is not common, but where it occurs it is distinguished from the chlorite by its extinction angle of 15°. Introductions along a vein structure have given calcite, quartz and albite-oligoclase.

No. (9024), from locality 85, is a light grey, fine grained basaltic rock in which the amygdales are partially filled with radiating needles of dark green epidote, actinolite and chlorite.

No. (9022), from locality 82, is a fairly typical melaphyre in appearance, having porphyritic plagioclase set in a purplish, fine grained groundmass spotted with green silicate. Amygdales are filled with calcite.

In thin section plagioclase laths show albite and Braveno twinning, while some Carlsbad is evident; composition is $Ab_{55}An_{45}$, andesine. Magnetite and antigorite form pseudomorphs after olivine. What appears to have been red-brown iddingsite has been hydrated to amorphous limonite.

The groundmass is holocrystalline intersertal in texture with microcrystalline patches. In this the felspar is less basic than the phenocrysts: $Ab_{66}An_{34}$, andesine. Chlorite and calcite replace nearly all original ferromagnesian. Minor accessories include ilmenite, leucoxene, magnetite and apatite.

The vesicles show zonal arrangement in which the inner zone is occupied by finely divided calcite flakes, followed by radiating vein structure of green pleochroic chlorite, and non-pleochroic matted chlorite. Sometimes within this zone there is a very thin calcite, felspar, quartz deuteric ring armoured by magnetite and haematite.

D—Fine grained non-amygdaloidal melaphyres

This group represents the non-amygdaloidal melaphyres which are usually dense, dark and fine grained, and often represent the fine grained equivalents of the preceding groups, such as (9023) corresponding to (9024). The same outcrop shows an even more pronounced amygdaloidal structure. Microscopically examined, (9032) has all the indications of being a spilite.

No. (9023) has an intergranular texture with a slight parallel banding which is much more evident in the hand-specimen. The felspar is in frayed laths showing very poor multiple twinning and is albite-oligoclase. The uralite is in the form of light green actinolite with $Z \Delta c$ 20°. Chlorite is not abundant.

No. (9030), from locality 78, is similar to (9023) but a little coarser grained. In this section the texture is intersertal. The plagioclase is albite. Actinolite is abundant as fibrous and compact laths: $Z \Delta c$ 15°, biaxial (—ve), $2V = 80°$. The remaining minerals are subordinate and include epidote, chlorite in small laths and fibrous to matted structures. Magnetite and calcite and clear quartz are of a secondary nature. Scapolite may be present.

No. (9032), from locality 71, is dark grey, very fine grained rock, in which vesicles are filled with rhomb-shaped porphyroblasts of siderite.

In thin section the rock is holocrystalline with an intersertal texture of the three main minerals, plagioclase, chlorite and magnetite. The felspar is difficult to determine, due to alteration, and very little residual twinning may be seen. The laths are broken and mottled near extinction: R.I. $<$ b, thus albite-oligoclase.

Chlorite is much more abundant than first appears, due to its very light green to colourless appearance. Magnetite occurs in very great quantity, suggestive of original iron-rich ferromagnesians. Calcite, biotite and rutile are present. Siderite and calcite rhombs grow in the general rock base and indicate a certain amount of thermal metamorphism to form these porphyroblasts. In addition to this, biotite occurs within their limits, indicating combination of sericite, muscovite, calcite and iron under the thermal conditions.

ASSOCIATED ROCKS

Associated with the basic rocks of Blinman area are several outcrops of gneiss described by Howchin as gneissic granites, and later as conglomerate paragneisses by Benson. However, a clue to their origin is seen at locality 157, where a pegmatitic rock has been intruded into a brecciated quartzite and purple slate. About it is a small iron-rich aureole. This rock, (9019), is principally microcline perthite, oligoclase, quartz, and a great number of accessories, including biotite, magnetite, sphene, rutile, zircon, apatite, haematite and pyrite.

In this section the gneiss at locality 172 is very similar to this in mineral content, with the exception that it contains more biotite and has suffered stress during emplacement.

No (9019), from locality 1597, is a coarse grained pink rock consisting of large crystals of buff to flesh-red felspar, colourless quartz and odd patches of black micaceous material.

In thin section the rock is holocrystalline, hypidiomorphic granular. The chief mineral is plagioclase twinned on the albite and combined albite-pericline laws with maximum extinction of 6°. R.I. > balsam indicates $Ab_{90}An_{10}$, oligoclase. It is biaxial (+ ve), 2V approaching 90°. It is severely stressed and shows undulose extinction to a high degree; the twinning planes are stressed and buckled to such a degree as to sheer along definite planes as in false cleavage.

Quartz is in anhedral crystals, showing peripheral granulation; its optical figure varies from uniaxial to biaxial with small 2V. Microcline perthite shows exsolution of albite. The relief of this albite is less than that of the microcline, and the figure is biaxial (+ ve), 2V = 75°, while the microcline is biaxial (— ve), 2V = 80°.

No. (9037), from locality 172, is a coarse grained gnessic rock containing buff to flesh coloured felspar, clear quartz with schistose bands of biotite.

Microscopically the rock is granulose with a suggestion of gneissic structure. Post-crystallization cataclastic effects have commenced myloniza-tion along parallel zones of both the felspar and quartz, giving rise to fine sericite and chlorite about lensed felspar and quartz. Microcline perthite occurs as turbid xenoblastic crystals sheared in the peripheral zones and in general having undulose extinction, low relief, biaxial (— ve) with a large optical axial angle. Plagioclase is not common; it is slightly turbid, due to incipient decomposition: R.I.< b, biaxial (+ ve), 2V approaching 90°. And therefore $Ab_{90}An_{10}$, oligoclase.

Quartz is cloudy due to inclusions, and shows marked peripheral granu-lation, causing undulose extinction and an optic axial angle up to 20°. The primary mica is biotite, which is strongly pleochroic: X = light straw yellow, Y = Z = dark green-brown. It is biaxial (— ve), 2V = 10/12 degrees as in (9019).

The granulation has developed parallel to gneissosity, with the result that secondary sericite has developed with the biotite. Accessories include magnetite, limonite, sphene, chlorite and zircon included in the biotite.

Apart from such pegmatites, there occurs an abundant suite of para-gneisses which have resulted from the combined action of shearing stress coupled with the heat of the basic intrusions. This adequately explains the limited extent of each individual occurrence.

Generally the intrusions are small or were quickly cooled, so that contact effects on the immediate surrounding rocks are small. However, where a hornfels would be expected in the surrounding slates, it is repeatedly found that coarse gneisses have formed in its stead. In the case of locality 7, gradations occur from slate to bimica-schist to coarsely foliated biotite-gneiss in which coarsely saccharoidal quartz bands nearly a quarter of an inch thick alternate with micaceous bands.

Associated with gneisses at two localities, 4 and 200, are occurrences of talc schists, such as B137. In the hand specimen the rock is light-green to grey and greasy, with the micaceous flakes in schistose arrangement. In thin section the talc is in colourless flakes and laths with extinctions of 3°, and is distinguished from muscovite by its lower axial angle. Other minerals are quite accessory and include amorphous limonitic material, golden-brown rutile and magnetite, which is arranged in single and double sets of parallel stringers, showing the presence of former twinning so commonly seen in the uralitic amphibole of the area. The present form has possibly resulted from the pneumatolytic alteration of a dolerite. In both cases the outcrops occur in the centre of gneissic bodies.

ACKNOWLEDGMENT

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THE SOILS, GEOLOGY AND VEGETATION OF NORTH-WESTERN SOUTH AUSTRALIA

BY R. W. JESSUP

Summary

The area described is approximately that which lies north of the transcontinental railway, west of Lake Torrens and Eyre, and westward toward the edge of the Nullarbor Plain.

THE SOILS, GEOLOGY AND VEGETATION OF NORTH-WESTERN SOUTH AUSTRALIA

By R. W. Jessup, M.Sc. *

[Read 12 April 1951]

Contents

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SUMMARY

The area described is approximately that which lies north of the transcontinental railway, west of Lakes Torrens and Eyre, and westward toward the edge of the Nullarbor Plain.

The average annual rainfall varies from $4\frac{1}{2}''$–$7''$. Prolonged droughts are common. The introduced and native animal populations are discussed briefly.

The rocks are mostly sedimentaries — Precambrian-Cambrian complex (largely quartzites), Jurassic sandstones, Cretaceous shales and Pleistocene alluvia. Recent wind-blown sands are widespread in the south. Vast plains from 200 to 500 feet above sea level dominate the topography.

Silicification of the surface (Cretaceous) deposits occurred during the earlier and later Pliocene, with a period between during which the resultant soils and the Cretaceous shales were variously truncated. Further truncation of the Pliocene soils and the Cretaceous shales occurred in the Pleistocene, resulting in exposure of underlying Jurassic sandstones in the south. Alluvium was also deposited in the Pleistocene.

The surface sands were stripped off the Pliocene soils in the arid Recent, and sands formed from the exposed Jurassic sandstones were resorted. Sandhills formed upon soils derived from Pleistocene alluvia and gypsum and sodium chloride accumulated in the soils. Pedological evidence indicates four moisture regimes during the Recent.

The type of soil formed from the Cretaceous shales depends upon the extent of truncation of the profiles. Over the tableland areas (preserved Pliocene topography) the soil is a deep clay with a surface mantle of billy gibbers derived from break-up of the siliceous B horizon of the Pliocene soil. Crabholes are developed and the soil contains heavy gypsum but no lime.

Shallower clay soils have resulted from either Pleistocene truncation of the deep clays or were formed during the second period of silicification from shale exposed by the erosion which occurred in the inter-silicification period. Crabholes may be present in these shallow clays and the soil contains heavy gypsum and a trace of lime. Billy gibbers again occur on the surface.

The Pliocene soils were completely removed from large areas in the Pleistocene to expose bleached shale upon which a very shallow soil has subsequently formed. Pleistocene erosion not only resulted in loss of part or all of the Pliocene soil but often caused complete or almost complete truncation of the Cretaceous shale itself. A very shallow soil overlying limestone hardpan has subsequently formed where a shallow layer of shale remained.

Two different sandy and calcareous soils developed where the Cretaceous beds were completely eroded away and the underlying sandstone was exposed. The shallow sands constitute Bon Bon soil and the deeper sands constitute Wirraminna soil. Coondambo and Mount Eba soils have developed upon Pleistocene alluvium. They both consist of shallow sand over red clay and contain lime and gypsum.

The billy gibbers vary considerably in their structure. Four different types are described. Accelerated erosion has been generally insignificant.

The vegetation consists mainly of chenopodiaceous shrub steppe communities on the heavier textured soils, and acacia woodlands on sandy soils. Two or more associations are commonly grouped together to form association complexes.

The dominant shrubs (12"-36" high) of the shrub-steppe communities vary in their lateral spacing but are rarely touching. The woodlands, which are fairly open, consist of trees 16 to 24 feet high. Beneath the trees there may be an understorey of shrubs with perennial grasses dominating the ground layer, or the shrubs may be absent, depending upon the depth of sand in the soil. Severe tree death has occurred in the woodlands and little regeneration is taking place. The shrub steppe areas may be uniformly bushed but in crabhole country growth is restricted to the depressions, the shelves being too arid and too saline. During drought times the ground between the shrubs and trees is bare.

The trees and shrubs provide a drought reserve of feed, but in prolonged droughts the trees are more valuable because the shrubs become defoliated. Over-grazing depletes the palatable species and causes thinning of the dominant shrubs and increase in the amount of bindyi (*Bassia* spp.). The high protein content of the chenopods is largely responsible for the production of large-framed sheep and high wool yields.

Detailed floristic lists of the species occurring in the associations are given and their relative palatabilities are rated.

The delineation of the boundaries of the different vegetation associations alone does not give an adequate picture of the grazing potential, as it is also necessary to indicate the state of preservation of the country. Five stages of degeneration of bush dominant country are recognised and defined quantitatively, and a portion of the North-West has been mapped on this basis. Two plans have been prepared, one showing the estimated original bush densities prior to stocking and another showing the present densities. From these two plans the amount of bush lost through grazing has been calculated.

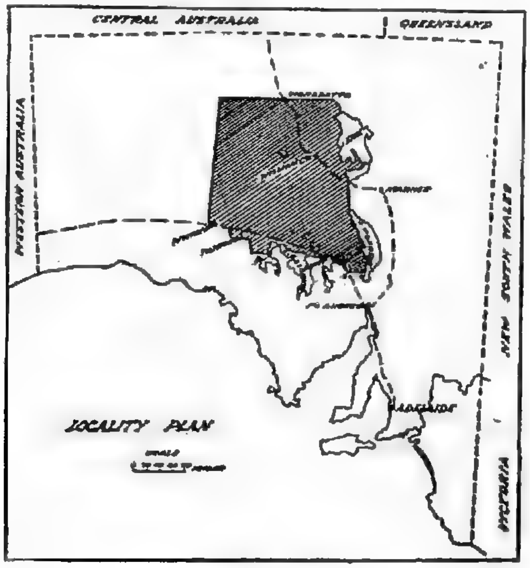


Fig. 1

INTRODUCTION

In 1943 the writer was appointed to the Soil Conservation Branch of the Department of Agriculture to investigate matters pertaining to soil erosion in the arid pastoral areas of South Australia and to provide data that might guide the Government and the pastoralists in the framing of policy with respect to these areas. The work reported herein is a comprehensive review of conditions in the north-western portion of the State, the boundaries of the area being shown in Figure 1. Field investigations were carried out during the period 1945-1950. Prior to the commencement of this work very little precise knowledge of the soils, vegetation and geology of this region was

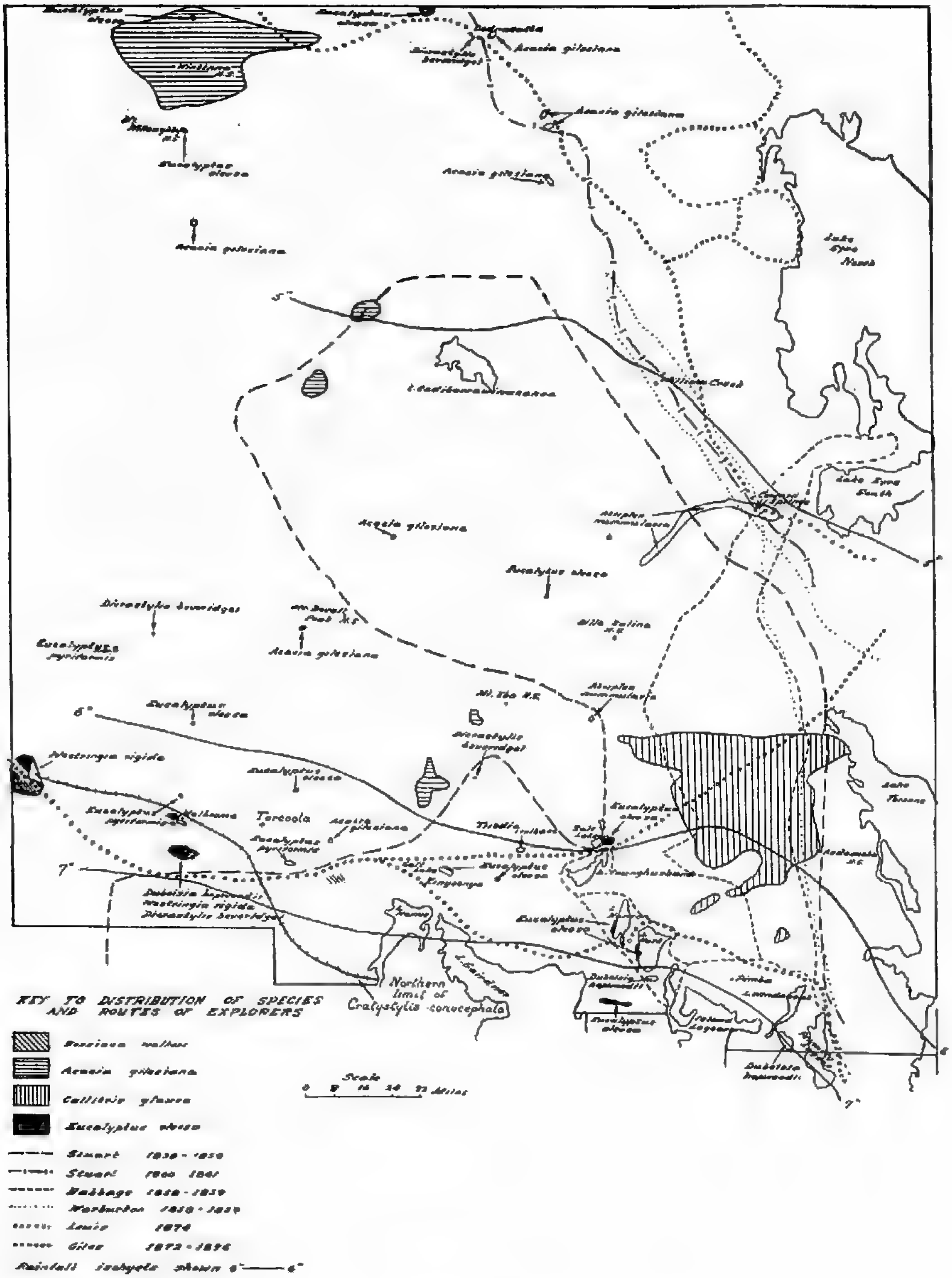


Fig. 2
Showing routes of explorers, rainfall isohyets and distribution of certain plants.

available. A paper dealing with the geography of the area is being published in the journal of the Royal Geographical Society of South Australia.

The southern portion of the North-West with an area of 23,000 square miles is used for the grazing of sheep, while the northern portion (28,000 square miles) carries cattle. Throughout these areas grazing is dependent principally upon native plant species and considerable damage to the perennial plant cover has resulted through overgrazing and other factors.

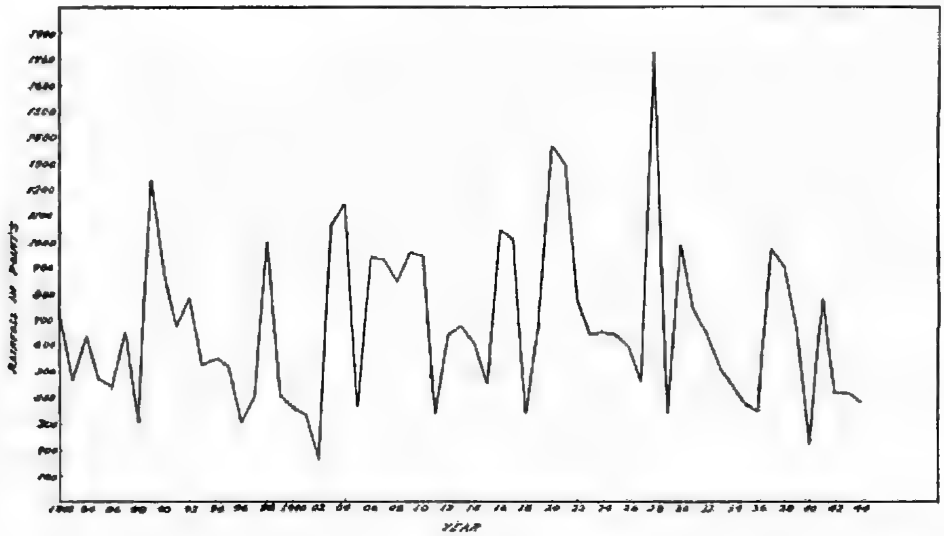


Fig. 3

Graph of annual rainfall of South Gap station for the years 1882 to 1944.

CLIMATE

The average annual rainfall varies from about $4\frac{1}{2}''$ in the Lake Eyre region to $7''$ in the south (figure 2). However, the average figure has little significance. Thus South Gap Station, which has an average of 652 points per annum for the period 1882 to 1944, has varied in yearly rainfall from a minimum of 168 points in 1902 to a maximum of 1,730 points in 1928. The fluctuations in annual rainfall for South Gap are shown in figure 3.

There is no marked seasonal rainfall as the area lies in a zone where the limits of the southern winter rainfall and the northern monsoonal summer rainfall systems overlap (Table I).

TABLE I

Average monthly rainfalls (in points)

	No. of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Oodnadatta	51	71	63	43	21	30	63	20	19	26	45	33	42	476
Tarcoola	28	34	71	46	36	65	82	53	71	56	71	53	62	700

The southern portion of the North-West as illustrated by the recordings for Tarcoola (Table II), has its greatest number of rainy days during the winter months May, June, July and August and the summer months November and December. As shown by the Oodnadatta record, in the north the

greatest number of rainy days occurs in the summer months (October, November, December and February) and the winter months June, July and August.

TABLE II

Average number of rainy days

	No. of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Tarcoola	8	2.3	3.1	2.1	3.3	3.4	4.4	5.1	4.5	1.8	3.0	3.4	3.8
Oodnadatta	4	2.5	5.3	2.3	1.3	1.5	3.0	2.8	4.0	2.3	2.8	3.5	4.3

In the southern portion of the North-West rains of greatest intensity fall during the summer months (Table III). Further north the intensity of the winter rains is also fairly high. The records for Oodnadatta are only available for a period of four years, but they might be expected to give some indication of conditions.

TABLE III

Average rainfall per rainy day

	No. of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Oodnadatta	4	28	12	19	16	20	21	7	5	11	16	10	10
Tarcoola	8	15	23	22	10	19	19	10	16	31	24	16	16

Jessup (1948) has pointed out that severe wind or hail storms occasionally sweep through narrow strips of pastoral country causing much damage to the vegetation. This is illustrated in Plate XIII, Figures 1 and 2.

Figures indicating the temperature regime are shown in Tables IV, V. VI and VII.

TABLE IV

Mean monthly temperatures of Tarcoola and Oodnadatta

	No. of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Tarcoola	18	78.7	78.5	74.4	64.9	58.4	51.9	51.3	54.3	59.9	66.1	71.7	76.0
Oodnadatta	55	83.4	82.9	79.4	70.1	60.7	55.1	54.3	58.4	66.6	71.1	78.3	83.5

TABLE V

Number of days for each month when the maximum temperature is 100° F. or more

	No. of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Tarcoola	8	9.5	6.8	2.1	.3	0	0	0	0	0	.4	3.9	6.3
Oodnadatta	4	16.3	11.0	1.8	0	0	0	0	0	.2	2.0	5.3	8.5

TABLE VI

Number of days when the minimum temperature is 40° F. or less

	No. of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Tarcoola	8	0	0	0	0	5.1	11.9	13.3	9.9	4.5	.9	0	0
Oodnadatta	4	0	0	0	0	.3	4.3	5.0	1.0	0	0	0	0

TABLE VII

Normal mean maximum and normal mean minimum temperatures for each month for William Creek and Tarcoola

	Yrs.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yr.
William Creek—														
Maximum	39	96.3	96.4	89.7	80.3	71.4	65.2	64.5	68.1	76.3	84.4	90.0	95.3	81.6
Minimum	39	68.8	69.6	63.5	55.0	47.4	43.2	40.7	43.5	49.0	56.3	63.7	67.4	55.6
Tarcoola—														
Maximum	18	93.8	94.1	89.5	79.1	71.8	64.6	64.5	67.9	74.9	81.8	87.6	91.8	80.1
Minimum	18	63.5	63.0	59.3	50.7	45.0	39.3	37.9	40.6	45.0	50.5	55.8	60.1	50.9

Frosts are of extremely rare occurrence at Oodnadatta, but for the six years 1943-1948 inclusive, the following are the total days for each month when the minimum temperature has been 32° or under at Tarcoola—May 5 days, June 23, July 26, August 9 and September 3. The other months are frost-free.

Although Yudnapinna Station lies slightly to the south of the area dealt with in this paper, the figures in Table VIII, which shows the average greatest daily range of temperatures in degrees Fahrenheit for the period 1941-1948, will be representative of the North-West generally. The greatest daily range occurs during the summer months.

TABLE VIII

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
41.0	37.9	36.9	35.2	33.9	32.9	34.2	37.1	40.6	41.4	41.5	42.3

Evaporation is high and relative humidity is low, particularly during the summer (Table (IX).

TABLE IX

	No. Yrs.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Yudnapinna—													
Evaporation in ″ ..	8	14.6	12.2	10.6	6.8	4.3	2.8	3.0	4.1	6.5	9.1	11.4	13.3
Tarcoola—													
Saturation deficit Mean, 9.00 a.m.	15	.513	.523	.441	.170	.167	.096	.100	.148	.239	.330	.471	.518
Mean relative humidity (saturation = 100)	39	32	33	36	43	51	60	55	48	38	31	30	30

Prevailing winds are from the south-east, although the direction of the winds tends to be variable during the winter months. On account of the tendency of sheep to graze into the wind, the prevailing south-easterly wind results in concentrated grazing in the south-eastern corners of paddocks. The direction of the prevailing winds must have changed since the time the east-west trending sandhills were built up, since Bagnold (1941) has shown that in seif dunes the long axis of the dune is aligned parallel to the direction of the prevailing wind. Furthermore, lunettes, which are aeolian accumulations, are found along the eastern margins of the salt lakes in the North-West. They could only form in this position under the influence of prevailing westerly winds. These east-west trending dunes and lunettes are discussed in the section dealing with geology.

SHEEP, CATTLE AND OTHER ANIMALS

The sheep carried in the pastoral country are large-framed, plain-bodied Merinos (Plate XIII, Figure 3). Fleece weight per head of sheep naturally varies considerably according to the seasons, but a cut of 12 pounds for grown ewes and 13 pounds for grown wethers is an average figure. The wool has a count of 60-64's.

Blowflies are the chief pest of the sheep industry, and to reduce the incidence of fly strike the sheep are generally crutched once a year, and the Mules operation is becoming more widely used of recent years. Recently lice have appeared in the sheep of the North-West, and several stations are dipping to control it. Tick are absent. Wild dogs are now a serious pest only on the most northerly of the sheep stations, that is, those adjacent to the cattle country. One dingo can, however, kill a large number of sheep in

a short time, and their presence in the unfenced cattle country necessitates any sheep carried there being shepherded. Shearing is carried out during either of two periods—February to March or August to September.

The cattle carried on the stations are Shorthorns or Herefords (Plate XIII, Figure 4).

Stock Numbers

The numbers of cattle and sheep carried fluctuate according to the seasons, rising in good years and falling during drought times. Sheep numbers for the whole of the sheep country covered in this survey have fluctuated from a maximum of 410,000 in 1939 to 145,000 in 1946 (Figure 4), while cattle have varied from 13,000 in 1940 to 30,000 in 1947 in the northern cattle country. In addition to the cattle, a few sheep are shepherded in the cattle country. Their numbers have varied from 2,500 in 1935 to 8,000 in 1948.

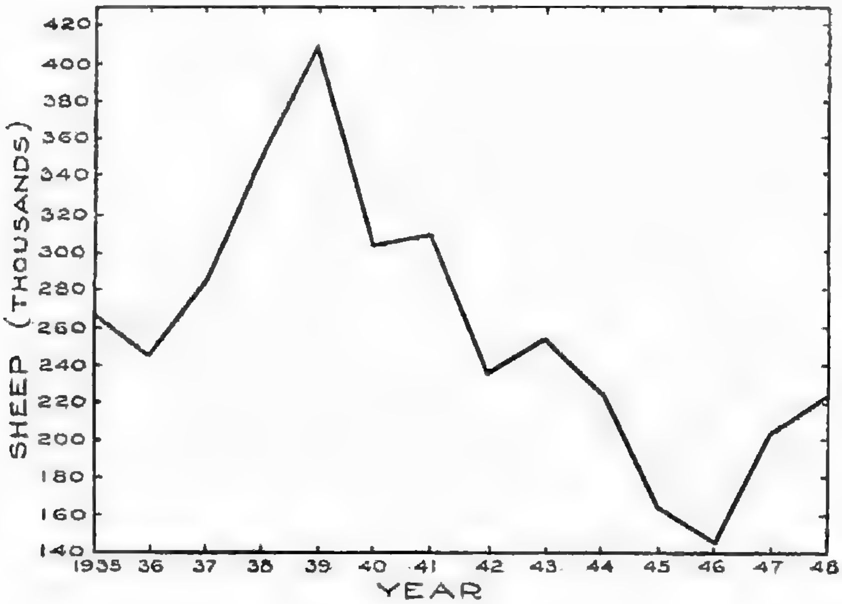


Fig. 4

Owing to this variation in cattle and sheep numbers according to seasonal conditions, the arid pastoral areas have no fixed carrying capacity per square mile of country. Only the drought-resistant perennial vegetation remains under drought conditions, and it may even be difficult to hold a flock of ewes from which to breed when the seasons improve. On the other hand, in good years there is such a wealth of herbage and grass that the perennial vegetation is scarcely grazed and sheep numbers can be greatly increased without harm to the permanent plant cover. The danger is, of course, that at any time a protracted dry period may set in. If sheep numbers are not reduced at the onset of the drought, but are held in the hope that rain will soon fall, not only is the country damaged but eventually the stock either have to be sold at a very low price or it may be impossible to market them, depending upon conditions in the higher rainfall country to the south. Consequently pastoralists now generally build up their flocks to numbers that can be carried in an "average" season.

As indicated above, pastoral country has no fixed carrying capacity and the fluctuations from year to year in stock numbers are great. In spite of this it is of interest to know what stock the North-West as a whole is carrying to the square mile.

It is standard practice to work out the average stocking rate per square mile of country by dividing the average number of sheep carried by the area of the country in square miles. If the following stations are considered on this basis, namely, Mulgathing, Malbooma, Wilgena, Bulgunnia, McDouall Peak, Ingomar, Mount Eba, Bon Bon, Mt. Vivian, Miller's Creek, Coondambo, Wirraminna, Parakylia and Roxby Downs, with a total area of 14,500 square miles and carrying an average of 204,000 sheep for the period 1935-43, the average carrying capacity per square mile is 14·3 sheep. To arrive at this figure 200 square miles have been deducted from the total area of the stations, since this represents the area of salt lakes.

However, this average figure of 14·3 sheep per square mile for the 14 stations as a whole is misleading, because most of them have some areas which are ungrazed or grazed only very lightly. Thus a total of 2,100 square miles is made up of paddocks which do not contain any stock water. The greater portion of this area is not grazed, while other of the paddocks carry stock during very good seasons only, that is, when there is sufficient succulent feed to enable the sheep to exist without water.

In addition to this unwatered country we have to consider that sheep do not graze beyond a four-mile radius of water except after very good rains, when surface water or succulent feed is available. Even when these favourable conditions prevail not all the sheep in the paddock will be grazing beyond four miles of the water. The areas which carry the stock most of the time, and particularly during the critical drought periods, lie, therefore, within four miles of permanent or semi-permanent water.

If the positions of the watering points in each paddock of the 14 stations mentioned above are considered, we find that 8,650 square miles are within four miles of water. This area is carrying stock at the rate of 23·6 sheep to the square mile, and the writer considers that this figure is a more accurate indication of the average stocking rate of the portions of the North-West which actually support sheep. It does not necessarily imply that the stocking is excessive. Until more research stations similar to Yudnapinna (Woodroofe, 1941) but using larger paddocks, are located in the different vegetation types of the North-West, no significant figures for carrying capacity will be available, nor will we know what the area of paddocks should be to balance efficient utilization of forage against economic returns.

At present many paddocks are far too big. Even when the small "holding" paddocks around woolsheds are included the total number of paddocks in the 14 stations is only 442, giving an average size of about 32 square miles.

The total number of waters on these stations is 360. This represents the sum of all watering points at bores, wells and dams as well as tanks along pipelines. On an average, therefore, there is a watering point for every 39·7 square miles of country. To avoid damage to the bush cover through excessive tramping, it is probable that no more than about 600 sheep should regularly water at any one point.

Rabbits

Although stock are the principal cause of the degeneration that has occurred in the pastoral country, nevertheless rabbits have played a very considerable part.

Rabbit numbers fluctuate enormously according to the seasons. Good years result in them breeding up to such an extent that they soon reach plague numbers and the damage they do is everywhere evident. With the onset of hot, dry weather and drying-off of herbage and grass they die quickly and in such numbers that the air in places becomes polluted with the smell of rotting carcases. After a while it is possible to drive hundreds of miles and scarcely see any rabbits at all. While the damage done by a big rabbit population is easily seen, the difficulty is to assess the damage caused by a medium population.

During 1948 rabbits reached plague numbers in the North-West, but no areas of saltbush or bluebush were actually destroyed by them. On the other hand, many of the bushes suffered some damage, as it was usual to find a litter of twigs on the ground around the base of the bushes. Rabbits, therefore, cannot be held directly responsible for death of saltbush and bluebush except under rare circumstances (see Plate XIV, Figure 1). In fact, as Ratcliffe (1936) has observed, the most vigorous bushes are often found in and around rabbit warrens because of the extra moisture they receive. Rabbits have an important indirect effect upon the bush cover. Plagues only occur in good years when there is an abundance of herbage and grass, but enormous amounts of feed which would otherwise have been available to the stock when conditions become dry are consumed. As a result, stock are forced to graze bush earlier than they would if rabbits had been absent.

As soon as the feed dries off, rabbits are forced to seek moisture and large numbers commence to die. At this stage the worst period of destruction begins. Young shrubs and trees are ringbarked and killed to secure moisture. Even mature shrubs and trees with leaning trunks or intricate branches are climbed and the young shoots are barked (Plate XIV, Figure 2). During 1948, when the plague was at its worst, rabbits could be seen in shrubs throughout the North-West. Their activities could often be traced to a height of 15 feet above the ground in the easily-climbed dead-finish (*Acacia tetragonophylla*) and many rabbits died as a result of becoming caught among the branches.

Most shrub species suffered some damage but greatest devastation occurred among prickly Acacia (*Acacia victoriae*), dead-finish (*A. tetragonophylla*), mulgas (*A. aneura* and *A. brachystachya*) and species of *Cassia* (Plate XIV, Figure 3). *A. victoriae*, being a rapid grower, is not in danger of being exterminated in spite of the fact that most of the young plants and a great many of the mature ones were destroyed by rabbits in the 1948 plague. On the other hand, rabbits will eventually eliminate slow-growing species such as mulgas and myall. Not all the seedings of these trees were destroyed in 1948, but most of those that survived lost a portion of the bark from their stems. Unless they mature before the next plague (and this is most unlikely) the seedlings that survived will probably be ringbarked.

The numbers of warrens and consequently of rabbits varies according to the type of country. Warrens are rarely found in the clay soils of the Arcoona, Coober Pedy, Mt. Eba or Coondambo types, but are very common in Twins soil and sandy and calcareous soil areas. The sandy soils are those that support trees and the greatest variety of shrubs, and it is unfortunate that the rabbit population is highest in these areas where the perennial vegetation is most susceptible to damage.

It is difficult to control and impossible to eliminate rabbits from pastoral areas by any known technique because of the large areas involved and comparatively few personnel.

Native Animals and Birds

The essential difference in grazing habit between the native animals and birds, and sheep and cattle, is that the former are migratory while the latter are confined to specific areas. Kangaroos (*Macropus rufus*) are the most numerous of the native species and have the greatest effect on the pastures. During droughts they congregate wherever localized thunderstorms may have resulted in a growth of herbage and grass. At other times they are most numerous in paddocks which are not carrying stock, and as a result they decrease the benefits obtained by "spelling" country. While kangaroos are destroyed in large numbers it is probable that they have increased since white settlement owing to the improved water supply.

Birds like the emu (*Dromaius novae-hollandiae*) which occurs throughout the area, and the native turkey (*Eupodotis australis*) which is only seen in good seasons, are not sufficiently numerous to have any significant effect upon the pastures. However, galahs (*Cacatua roseicapilla*), which occur in large numbers, undoubtedly consume large quantities of seed.

Fossil evidence of the former distribution of wombats (*Lafiorhinus latifrons*) and mallee fowls (*Leipoa ocellata*) is found in portions of the North-West. Recession of these species probably occurred in the arid Recent. Mounds (nests) of the mallee fowl occur in dense mulga country in the southern portions of Mt. Vivian and Bon Bon Stations. This was the most northerly occurrence of the species in the area covered in this survey. Old burrows made by wombats are found in calcareous soils as far north as Commonwealth Hill Station.

GEOLOGY AND PHYSIOGRAPHY

Considering north-western South Australia as a whole, the outstanding feature of the geology is the presence of predominantly flat-lying sedimentary rocks, consisting of Precambrian-Cambrian complex, Jurassic and Cretaceous sediments and Pleistocene alluvia. Recent wind-blown sands are a widespread feature especially of the southern portion. Over these vast plains rock outcrops are uncommon, the surface generally being covered with Recent sands, transported material, or soils derived from the underlying strata.

Precambrian-Cambrian Complex

West of the Lake Torrens depression there is a widespread occurrence of almost horizontally-bedded sedimentary rock which have been variously referred to the Proterozoic (Adelaide Series), Cambrian, or the Ordovician systems. The sediments are largely quartzites, but include dolomites, conglomerates and green and brown shales. So far they have proved unfossiliferous.

On lithological grounds the beds were originally assigned to the Ordovician. Subsequently there has been an increasing tendency to link the individual formations with various horizons of the vast sedimentary sequence (Adelaide Series and Cambrian) of the Flinders geosyncline lying to the east (David 1932; Segnit 1939; Dickinson 1942). Mawson (1947) has suggested that these formations may be equivalents of the basal portion of the Adelaide Series and agrees with Sprigg (personal communication) that some horizons may include the basal Cambrian quartzite. In early Cambrian times the sea is known to have transgressed the ancient land massif in the Yorke Peninsula locality and from this it may be anticipated that a similar overlapping would also occur further north.

According to Jack (1930), there are three main horizons in the tablelands west of Lake Torrens. The deepest members exposed are shales. Over these were deposited sandstones which have subsquently been partly altered to quartzites, while the uppermost formation is a limestone of sub-crystalline structure. Erosion has completely removed the limestone and exposed the more resistant quartzite in the higher tableland areas. Upon these formations, according to Jack, a much younger one, the Eyrian, has been laid down, the bulk consisting of whitish and mauve clays.

Segnit (1939) gives the following sequence and age of beds:

duricrust	Lower Tertiary (Eyrian)
white and mauve clay with boulders and sandstone	
white clay with boulders	Lower Cretaceous
sandstone	Jurassic?
limestone	Cambrian-Precambrian complex
quartzite-sandstone	
shale	

while Dickinson (1942) gives the following:

duricrust	Tertiary
white pipeclay	tentatively Cretaceous
sandstone	Cambrian-Precambrian complex
dolomitic limestone	
sandstone	
shale	

The writer has observed that west of the tableland country some of the bores and wells have penetrated quartzites below the Jurassic sands. These quartzites are encountered as far west as Bon Bon Station and there are small outcrops in the southern portion of adjacent Wilgena Station. The western boundary of Bon Bon is the western limit, and the east-west railway line west of Kingoonya the northern limit of the quartzites.

In addition to this large area of Precambrian-Cambrian rocks west of Lake Torrens, there are outcrops of granites and metamorphosed rocks of Precambrian age in the Kingoonya-Tarcoola locality and extending northwards to Commonwealth Hill Station. The felspar in the old granite or gneissic granite is weathered and kaolinized as a result of the high rainfall of the Pliocene. In addition to the kaolinization of the felspar, billy (1) pebbles

(1) Billy is the term given to the siliceous product resulting from solution and subsequent deposition of silica as distinct from laterite in which the accumulated material consists of oxides of iron and aluminium.

(remnants of the siliceous B horizon of a Pliocene soil profile) occur on the granites, indicating their pre-Pliocene age. These older rocks have been invaded by a younger granite which is less weathered (Plate XIV, Figure 4). South of Oodnadatta, in the Denison Range, rocks of Precambrian age form a north-south mountain range which rises abruptly from the plain on its eastern side (Plate XV, Figure 1).

Jurassic

Lying to the west and north of the Precambrian-Cambrian area of the Lake Torrens region and probably overlapping it as Segnit (1939) has indicated are beds of the Great Artesian Basin of Jurassic age. The Jurassics were the first deposits to be laid down over the ancient land surface and are the waterbearing beds of the artesian basin. They are essentially fresh-water deposits, the area then being a vast inland lake (Howchin 1929). The rocks are sandstones, sands, sandy clays and clays of various colours (white, brown, pink, green and yellow). Many of the bore logs show that the basal beds were grits, sandy gravel or waterworn quartz stones. Bores on Commonwealth Hill and Mulgathing (the most westerly stations) penetrate much coarser beds than bores further east such as in the Mt. Eba region, indicating that the westerly stations must be near the old Jurassic shore-line.

Rock outcrops of Jurassic age are very rare, the sandstones being usually covered by sandy soils derived from them or by Cretaceous beds. The only outcrops are very small and are found towards the southern limit of the Jurassic deposits, on Bon Bon Station (in the Gosse Range area), between Lake Labyrinth and Lake Harris on Wilgena Station and along the east-west railway line on Coondambo Station. The outcropping sandstones are very coarse-grained and their exposed surfaces have been silicified. West of Wirraminna Station then, the east-west railway line coincides approximately with the southern boundary of the Jurassic sea.

Cretaceous

During Cretaceous times the area in which Jurassic sediments were deposited and the Precambrian-Cambrian area west of Lake Torrens were invaded by the sea. A blue shale was deposited and for a time conditions were so cold that glacier ice was present and erratics of quartzite from the Precambrian-Cambrian and felspar porphyry, gneissic granite and granite from the Gawler Range-Tarcoola area were deposited (Jack 1939).

The upper layers of the blue shales were bleached to a white colour under the influence of the Pliocene climate and were also, in parts, silicified to form jasper. Precious opal is found in the bleached Cretaceous shale at Coober Pedy and Andamooka (Plate XV, Figure 2).

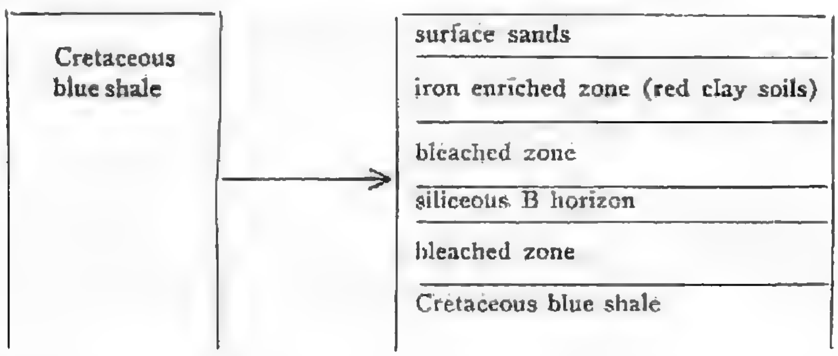
West of Wirraminna the east-west railway line roughly corresponds to the southern limit of the Cretaceous shale. In this area the shallow Cretaceous deposits have largely been eroded away or weathered to a clay soil which overlies the Jurassic sands. The most southerly outliers of Cretaceous age on Wirraminna Station (isolated flat-topped hills around the shores of Lake Hart) show a depth of 30 feet of bleached shale overlying the Precambrian-Cambrian rocks. East of Wirramanna, however, the Cretaceous shale extended further south. In fact, while the Cretaceous beds themselves have been weathered away, soils derived from Cretaceous shales occur in situ along Spencer Gulf in the vicinity of Port Augusta and Whyalla.

Tertiary Climates and their effects on the Older Geological Formations

The Pliocene is accepted by Whitehouse (1940) as being a period of high rainfall and warm temperatures. Steady uniform rains prevailed for the earlier and later portions with a period between of seasonal rains. During the periods of steady uniform rains, laterites and allied soils formed throughout much of Australia. However, there is evidence in the North-West which suggests that there must have been a considerable time-lapse between the two periods of silicification [2] because a portion of the inter-silicification period must have been arid. Thus some of the billy gibbers [3] are a conglomerate type and consist of waterworn pebbles and small stones resulting from break-up of the siliceous B horizon formed during the first period of silification subsequently cemented together by silica during the second period. The interesting point is that the pebbles and stones within the billy gibbers have red-brown ironstained surfaces similar to the gibbers themselves.

On Billa Kalina Station and north of Coward Springs there is further evidence to support the theory that there were two periods of silicification separated by a drier interval. Here non-fossiliferous siliceous limestones overlie bleached zone material. Billy gibbers resulting from break-up of the siliceous B horizon formed during the second period of silicification are scattered over the surface of the limestone which has been silicified in its upper layers by general infiltration of silica and by the formation of seams of quartz crystals through the limestone. At Moodlampnie Hill (Plate XV, Figure 3) on Miller's Creek Station, the limestones are about 20′ in thickness, while north of Coward Springs they are up to 40′ in thickness.

It is evident from the present physiography of the country that by the Pliocene the old land surface was eroded down to a peneplain. The dominant topographical features are the more or less preserved tableland areas (Pliocene land surface) and the flat-topped residual hills at a similar height above sea level that are scattered through what is now lower country. Under the influence of Pliocene rainfall, temperature and physiography, silicification of the surface (Cretaceous) deposits occurred in the earlier Pliocene, as follows:



(2) As no term has previously existed in soil literature the term silicification has been given to the process which results in the formation of profiles similar to those produced by laterization but in which a siliceous (billy) illuvial horizon is formed instead of a ferruginous one. Another essential difference between the profiles produced by silicification and those formed by laterization is that in the former there is no mottled zone.

(3) Gibbers is the term applied to the larger rock fragments which occur on the surface of the soil over large areas of inland Australia.

As a result of the change in the Pliocene from steady uniform rains to seasonal rains, the peneplain was dissected to varying extents. Over portions of the country it remained fairly well preserved, although some of the surface soil was removed, and break-up of the siliceous B horizon was initiated. Elsewhere the soil profile was completely removed and also some of the underlying Cretaceous shale. Then later in the Pliocene (if we accept the theory that both periods of silicification are of this age), uniform steady rains resulted in the second period of silicification. The result is that the Pliocene fossil soils occur at varying levels. There is no evidence that lowering of the water table has been a factor in producing soils at the different levels.

With the onset of a new cycle of erosion in post-Pliocene times, the peneplain residuals from the first Pliocene silicification period were again dissected to varying extents sometimes with complete removal of the soil and elsewhere by removal of the surface soil only. Break-up of the siliceous B horizon continued. The soils formed during the second period of silicification were similarly truncated and there were large areas from which the Pliocene soil was completely stripped, exposing the underlying bleached shale. Towards the southern limits of the Cretaceous deposits, that is, where they were thin, the shale itself was removed and the underlying Jurassic sands and sandstones exposed. Such was the fate of the Cretaceous sediments.

Much of this erosion probably occurred in the pluvial Pleistocene and at the same time alluvial material was deposited. The most interesting of these alluvial deposits is found in the Mt. Eba depression and in the watercourses feeding into it. This alluvium (or rather the soil subsequently formed from it) is described under the Mt. Eba soil (see soil section). Other areas of Pleistocene alluvia are found principally around the margins of salt lakes (see Coondambo soil).

To the south of the tablelands is a system of salt "lakes" of Pleistocene origin (Lakes Hart, Hanson, Island Lagoon, Gairdner, Harris, Windabout, and Pernatty Lagoon). During times of exceptionally heavy rains these "lakes" receive run-off water from the tableland country and may then contain a few inches of water over portions of their surface (Plate XV, Figure 4). This water is driven from shore to shore depending upon the direction and persistence of the winds, but is rapidly evaporated to leave behind the salt which it contained in solution.

Beneath the salt crust which varies in thickness from ¼" to 3" is a thin deposit (⅛" thick) of red slushy sand, with dark red-brown clay containing gypsum crystals below. The clay continues to a depth of about 18". Below this is a layer about 1 ft. in thickness of dark-brown sandy clay containing black inclusions of ferrous iron. These deposits are distinctly laminated. Below these alluvial horizons is red slushy sandy clay underlain by the sandy floor of the lake.

Structures allied to lunettes consisting of powdery gypsum and some grey siliceous sand are found along the eastern margins of the salt lakes. In typical lunettes the steeper slope is towards the lake (Stephens and Crocker 1946), but the lunettes associated with "lakes" in the North-West have the steeper slope on the side of the dune away from the lake. This is probably due to the lack of stabilization of the lunette dune by vegetation. These gypseous deposits must have been built up when conditions were somewhat moister than they are today, that is, before the formation of the salt crusts. Under present rainfall sodium chloride accumulates to form a crust over the lakes.

When the Pliocene land surface was eroded, isolated flat-topped hills composed of bleached Cretaceous shale remained scattered through the lower country (Plate XVI, Figure 1). These features were preserved as a result of their thicker billy cappings. Their flat tops are covered with billy boulders and their uniformly sloping sides are partly covered with billy scree. The hills, therefore, vary in colour when seen from a distance. If the slopes are billy-covered the hills appear red-brown while those in which bleached shale is exposed are white (Plate XVI, Figure 2). A shallow depth of red clay (part of the Pliocene soil profile) may remain on top of these residuals.

The exact depth to which the blue shale was bleached under the influence of the Pliocene climate is not known. Blue shale is never exposed in any of the residual hills. Opal diggings at Coober Pedy (up to a maximum depth of 90′) are located principally around the lower slopes of residual hills and penetrate bleached zone material throughout. Logs of bores on Miller's Creek Station indicate about 90′ of bleached shale (white above but becoming brown with depth) overlying blue shale. These bores are located in country from which considerable depths of bleached shale have been eroded. From the information available, then, bleaching must have taken place to the unusual depth of at least 120′.

Apart from slight iron-stainings (yellow, red or brown) on the surface of the weathered bleached shale fragments, indications of iron such as mottling are absent. The kaolinized fragments are themselves white and smooth-textured. Lateritic ironstone and gravel do not occur in the North-West.

While the billy on the surface of the tableland is in the form of polished gibbers, blocks of billy up to two feet in thickness and several feet across are found on the tops of the residual hills (Plate XVI, Figure 3). Most of the billy (the polished gibbers especially) has an iron-stained surface, the colour varying from red-brown to black. On the tableland surface, gibbers which have been iron-stained right through are occasionally found. These iron-impregnated stones usually occur in patches. On Miller's Creek Station funnel-shaped pieces of billy are common, each gibber having a curved base coming up to a conical peak, with a circular hole through the peak. Some of the circular cavities contain yellow ochre (limonite).

While much of the siliceous B horizon was broken up as a result of truncation of the overlying soil, over the comparatively well-preserved Pliocene land surface of the non-dissected tableland areas break-up of the B horizon must have proceeded below the soil surface, because the siliceous horizon formed within the bleached zone. The mantle of gibbers on the surface is the result of movement of the clay through alternate wetting and drying which causes the stones to be gradually moved upwards to the soil surface.

The surface sands formed as a result of the Pliocene silicifications were largely stripped off the old land surface during the arid Recent and deposited in the surrounding lower country. The sand contributed to both the sandhills and the sandy plains. A considerable thickness of surface sand must have covered the Pliocene soils to enable extensive sand dune areas to form within the tableland far removed from any Jurassic sandstone outcrops, the only other source of siliceous sand. Not all the sand was, however, stripped off or piled into these major dune areas, since there are still isolated sandhills superimposed upon the tableland clays in some localities.

In addition to this Recent stripping and resorting of the sands from the old land surface, sand derived from the Jurassic sandstones was also resorted. This sand was formed from the sandstones after Pleistocene erosion

had removed the overlying Cretaceous beds. As a result of the redistribution of the sand, the depth of the surface sands of the soils varies greatly over a small area and this in turn causes a complex vegetation pattern.

The gypsum and sodium chloride present in the soils must have accumulated after the Pleistocene since these soluble salts would be among the first leached out. It is certainly not suggested, however, that the sodium chloride originated as "cyclic" salt. Gypsum is particularly common in the heavier-textured soils, that is, the Pliocene fossil soils and the soils formed from the Pleistocene alluvia. It occurs within a few inches of the surface in the form of spherical aggregates of micro-crystals and increases in quantity with depth sometimes to the extent of forming crystalline lumps. Over the tablelands of the Lake Eyre region sheets of gypsum (selenite) up to 15″ in length and 5″ thick protrude from the surface of very friable "bulldusty" patches. Gypsum in the form of a loosely-cemented powdery mass is of general occurrence on the slopes of the residual hills. It has already been pointed out that gypsum (kopi) dunes are associated with the margins of salt lakes. Heavy deposits of gypsum are encountered in the bleached Cretaceous shale in which opals are obtained at Andamooka and Coober Pedy.

There is a correlation between the amount of gypsum in any site and the moisture status. In the well-drained sandy soils gypsum is usually absent, but it is heavy in the soils of the Mt. Eba depression and the Pliocene fossil soils where drainage is impeded and where the moisture status is comparatively high because of the presence of crabholes. The quantities of gypsum become even greater in claypans and salt lakes.

During the Recent period sandhills formed upon the soils derived from the Pleistocene alluvia in some localities. Conditions became moister following this period of aridity, and colonization and stabilization of the sandhills with mulga in the south and canegrass further north took place. However, some of the dunes superimposed upon the tableland, for example, in the Wirraminna, Roxby Downs, Arcoona area and some of those immediately surrounding it are unstable, being scantily vegetated with shrubs like sandhill wattle (*Acacia ligulata*) and hop-bush (*Dodonaea attenuata*), species which precede mulgas in the colonization of sandhills. These dunes are of more recent origin, in fact were built up after the moister period when the stable dunes were colonized with mulga. This indicates a change to somewhat more arid conditions during very recent geological times.

The second piece of evidence in support of a theory of very recent increase in aridity has already been given, namely, that under present climatic conditions sodium chloride is accumulating as a surface crust on the salt lakes whereas in the past there must have been a period when a salt crust was absent (see Plate XVI, Figure 4). If this were not so it is difficult to explain the kopi dunes around the eastern margins of the lakes because this gypsum has obviously been derived from the lake surfaces.

There remains to be discussed the origin of the lime in certain of the soils. Lime cannot be detected in the least truncated Pliocene fossil soil (Arcoona type) which is associated with the tableland country, but a trace of lime can often be found in Coober Pedy soil, that is, where the clay of the old land surface has been partly truncated. Coober Pedy soil profiles may actually be underlain by travertine limestone. Trace to heavy lime is found where all the clay has been removed from the Pliocene soil and bleached Cretaceous shale is exposed. Where the Cretaceous beds have been completely or almost completely eroded away heavy accumulations of lime are a constant feature of the soils. The amount of lime in the soils is therefore

greater with increased truncation which is correlated with increasing soil aridity. It has already been noted that the amount of gypsum in the soils decreases as soil aridity increases.

In the soils with heaviest accumulations, the lime is in the form of rubble overlying hardpan which is underlain by more rubble and friable lime. Small iron-coated billy pebbles are scattered through the lime zone.

The presence of billy pebbles in the lime zone suggests that Crocker's (1946) loessial theory probably accounts for the origin of the lime in the soils. Jack (1921) has suggested that gypsum is formed in the Cretaceous beds as a result of the interaction of lime and sulphates derived from iron pyrites. The writer has already pointed out that calcium is present in the form of carbonate in well-drained soils with low moisture status, while more and more of the calcium is present as gypsum in poorly drained sites, that is, gypsum accumulates where the moisture status of the soil is sufficient to enable sulphates and lime to react and leaching cannot take place. This explains why calcium can have originated as loessial lime and yet the boundary between soils with no lime (but heavy gypsum) and those with heavy lime can be sharply defined.

From pedological evidence, therefore, we can distinguish four moisture regimes during Recent geological times. The early Recent must have been arid because vegetation was largely destroyed. The desert sandhills were built-up, the sandy A horizons were stripped from the Pliocene soils and the surface sands in the sand sheets were re-sorted. Then rainfall must have increased to allow colonization of the sandhills and sandplains with trees. We have already noted that crystalline gypsum, frequently in the form of large sheets, is found on the tableland country today. This gypsum must have been in solution to have been precipitated in crystalline form so that during this moister period of the Recent there must have been a fairly shallow water table. This moist period then gave way to a drier one, during which the gypsum crystals were formed. In this drier period the newer unvegetated dunes formed on the tableland and about its margins in some localities. Rainfall was sufficient to prevent a salt crust from forming on the surface of the lakes.

Rainfall has continued to decline to the present day. During this period of increased aridity salt has accumulated on the surfaces of the lakes. Evidence from the distribution of myall (*Acacia sowdenii*) — see vegetation section—suggests that rainfall is now lower than it was when tree colonization was taking place.

Physiographic Features

The geological framework then is made up of flat-lying sediments while topographically the North-West consists of vast gently-rolling plains mostly between 200 and 500 feet above sea level. The highest hills are Dutton's Bluff (920 feet) and Mt. Gunson (850 feet), while the bed of Lake Eyre is 39 feet below sea level.

Hills and ranges are either residuals of the Pliocene landscape (Plate XVII, Figure 1) or composed of granite or metamorphosed rocks. They are usually less than 200 feet above the surrounding country. Much of the area is quite featureless, so much so that in some cases trigonometrical stations are located on sand ridges. Faulting has played no part in the elevation of the tablelands or residual hills. These features are due to differential erosion, the hills in particular owing their preservation to a thicker capping of billy.

The sandy southern and western portions of the North-West have a drainage pattern made up of short watercourses ending in "swamps" which

contain water only after heavy rains. Further north the tableland country is drained by well-defined creeks which run in an easterly direction and discharge water into Lake Eyre after heavy rains. Before they reach the lake, however, they flood out and consist of a mass of interlacing channels and long narrow waterholes. Practically all these "lakes" are really saltpans — depressing flat expanses with a salt crust or saline mud surface. Portions of the salt lakes are firm and will support a motor vehicle but elsewhere, particularly near the mouths of watercourses and creeks, they are very boggy. During exceptionally wet seasons which may occur one year in every ten, a few of the freshwater "lakes," for example Coolymilka Lake, Lake Richardson, Arcoona Lake and Lake Campbell contain appreciable quantities of water. All of these lakes are depressions within tableland country. Even the water in these becomes very brackish as they dry up.

Sandhills have an east-west trend in the southern portion of the North-West, but in the north their trend is north-west to south-east. The sand has been derived from two sources. Sandhills in the lower country surrounding the tablelands have accumulated sand from Jurassic sandstones weathered *in situ* and from the Pliocene soils. The flats between them are sandy. All the sand in the dunes which are superimposed upon the tableland has been derived from the sandy A horizons of the Pliocene soil. If these dunes are close together the interdune areas are sandy, but if they are scattered the flats between them consist of gibber-strewn clay soils of the Coober Pedy or Arcoona types.

Claypans generally occur in association with sandhills, either in the hollowed-out crests or more often on the flats between the dunes. They are flat expanses of red clay of variable shape but often roundish in outline and vary from a few yards to several miles across (Plate XVII, Figure 2). The surfaces of claypans are often littered with billy gibbers (Plate XVII, Figure 3), while gypsum occurs at shallow depths within the clay. After rains they may contain an inch or two of water, yellow in colour due to suspended clay. Claypans are not, however, restricted to sandhill areas, being frequently developed in Coondambo and sometimes in Wirraminna soil areas. They form in depressions where water containing suspended clay washed out of the sandy soils tends to lie.

The following is a typical claypan profile:

0–18" red clay
18–24" brown clay with moderate gypsum
24–36" (continuing) grey clay with heavy gypsum

Soil – Geology Relationships. The Surface Deposits

The type of soil developed upon the Cretaceous rocks depends essentially upon the truncation that has occurred in the profiles. Over the tableland areas where the Pliocene topography is fairly well preserved, the soil overlying the Cretaceous shale is a reddish-brown clay with a surface mantle of billy gibbers and rare glacial erratics which have weathered out of the parent material. The surface which is gently rolling and slopes towards drainage lines (creeks and watercourses) is characterized by a pattern of depressions (crabholes) with mounds (puffs) around the lower side of the crabholes. The clay is about 10 feet in depth and is underlain by bleached shale except in the Kingoonya region where the clay soil directly overlies Jurassic sandstone. In this area the Cretaceous beds were very shallow and were completely weathered to clay. The soil whose surface features are described above, that is, the Arcoona type, is the least truncated of the Pliocene

fossil soils. Morphologically it represents the Pliocene profile minus the sandy A horizons and some clay and with the siliceous B horizon broken up.

Shallower clay soils of the Coober Pedy type have resulted from either Pleistocene truncation of Arcoona soil or were formed during the second period of silicification from shale exposed by erosion which occurred in the Pliocene inter-silicification period.

The Pliocene profiles were completely removed over large areas in the Pleistocene to expose bleached shale. The light red-brown soil subsequently formed on the exposed shale is very shallow and has a surface cover of bleached shale fragments and billy pebbles. This is Twins soil. Pleistocene erosion not only resulted in loss of part or all of the Pliocene soil from Coober Pedy and Twins soil areas but often caused complete or almost complete truncation of the Cretaceous shale itself. Truncation of the shale had its most important pedological effects towards the limits of the Cretaceous sea where the beds were thin even when first laid down. All of this lower country surrounding areas where the Pliocene landscape is more or less preserved is characterized by soils containing large quantities of lime. A very shallow clay loam or clay soil overlying limestone hardpan was formed in post-Pleistocene times in areas where a shallow layer of Cretaceous shale remained. The limestone hardpan may overlie Jurassic sandstone or a shallow band of shale, depending upon the thickness of shale which survived the Pleistocene erosion. This, the Wilgena soil, has its surface more or less covered with iron-coated billy pebbles.

Two different sandy soils containing large quantities of lime developed where the Cretaceous beds were completely destroyed by erosion and the underlying Jurassic sandstones were exposed. Not all the sand in the soils was formed *in situ* from the underlying sandstones as some it was derived from the surface of the Pliocene soils during the arid Recent. Very shallow sands overlying limestone rubble and hardpan (Bon Bon soil) are present in areas from which sand was stripped during the redistributions of the arid Recent. Where comparatively deep red sand overlies limestone (Wirraminna soil) either the sand was not disturbed during the Recent or else these areas received some sand from the surface of the Bon Bon soil areas. Further accumulation of sand results in the formation of sandridges and sandhills. These aeolian accumulations may be superimposed upon a variety of geological materials.

In the Miller's Creek-Billa Kalina area a very shallow brown clay loam or loam soil (Miller's Creek type) has formed upon siliceous limestone. This limestone must have originated during the inter-silicification period of the Pliocene because shale that was bleached during the first period of silicification underlies it and billy pebbles (remnants of the siliceous B horizon of the soil formed during the second silicification period) are scattered over its surface.

Two different types of soil have formed on Pleistocene alluvia. The Mt. Eba soil which developed principally on alluvium in the Mt. Eba depression and along watercourses feeding into it has a shallow sandy surface overlying red clay. A mantle of billy pebbles occurs on the soil surface and billy pebbles are buried in the profile. As it is formed from transported parent material, Mt. Eba soil may overlie either bleached Cretaceous shale or Jurassic sandstone.

Coondambo soil, which also is formed from Pleistocene alluvium, consists of red clay overlain by shallow sand. Unlike the Mt. Eba soil, little or no billy is associated. Jurassic sandstone underlies the soil at shallow

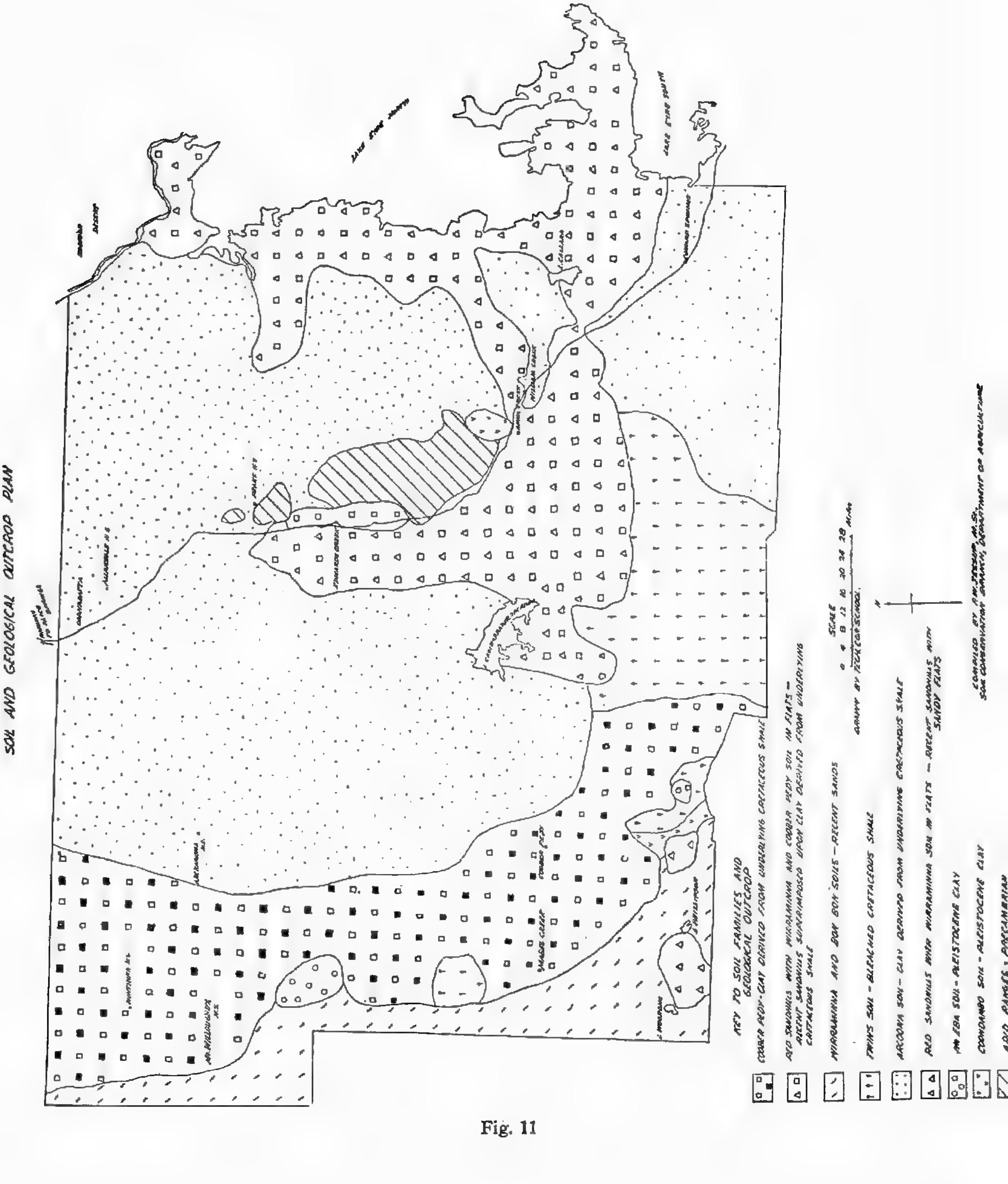

SOIL AND GEOLOGICAL OUTCROP PLAN
KEY TO SOIL FAMILIES AND GEOLOGICAL OUTCROP
COOBER PEDY - CLAY DERIVED FROM UNDERLYING CRETACEOUS SHALE
RED SANDHILLS WITH WIRRAMINNA AND COOBER PEDY SOIL IN FLATS — RECENT SANDHILLS SUPERIMPOSED UPON CLAY DERIVED FROM UNDERLYING CRETACEOUS SHALE
WIRRAMINNA AND BON BON SOILS — RECENT SANDS
TWINS SOIL - BLEACHED CRETACEOUS SHALE
ARCOONA SOIL — CLAY DERIVED FROM UNDERLYING CRETACEOUS SHALE
RED SANDHILLS WITH WIRRAMINNA SOIL IN FLATS — RECENT SANDHILLS WITH SANDY FLATS
ZEBA SOIL - PLEISTOCENE CLAY
COONDAMBO SOIL - PLEISTOCENE CLAY
ARID RANGES - PRECAMBRIAN
SCALE
0 4 8 12 16 20 24 28 Miles
DRAWN BY TECH.COR.SCHOOL.
N
COMPILED BY R.W. JESSUP, M.Sc.
SOIL CONSERVATION BRANCH, DEPARTMENT OF AGRICULTURE
LAKE EYRE NORTH
LAKE EYRE SOUTH
EDWARDS CREEK
WILLIAM CREEK
COWARD SPRINGS
STUARTS CREEK

Fig. 11

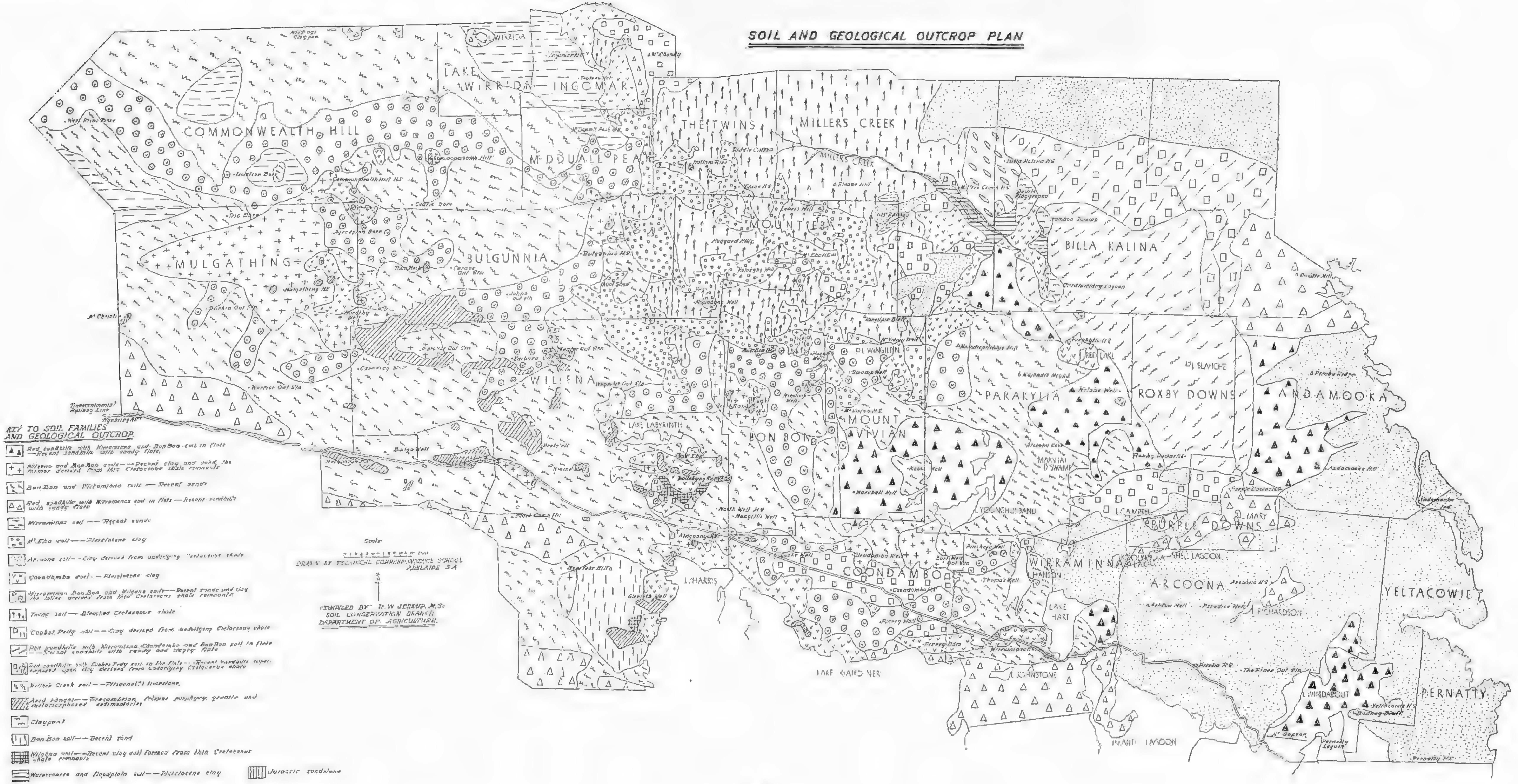
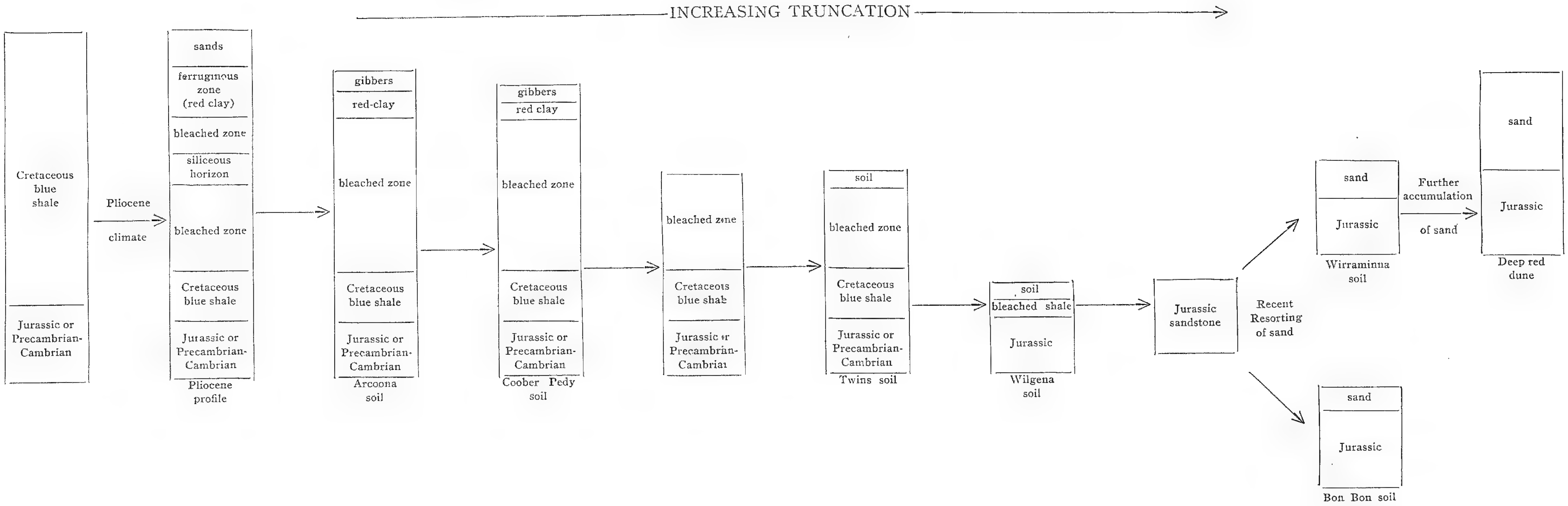

SOIL AND GEOLOGICAL OUTCROP PLAN
COMMONWEALTH HILL
LAKE WIRRIDA
INGOMAR
McDOUALL PEAK
THE TWINS
MILLERS CREEK
MULGATHING
BULGUNNIA
MOUNT EBA
BILLA KALINA
WILGENA
PARAKYLIA
ROXBY DOWNS
ANDAMOOKA
LAKE LABYRINTH
BON BON
MOUNT VIVIAN
PURPLE DOWNS
WIRRAMINNA
COONDAMBO
ARCOONA
YELTACOWIE
PERNATTY
L. HARRIS
LAKE GAIRDNER
ISLAND LAGOON
KEY TO SOIL FAMILIES AND GEOLOGICAL OUTCROP
Millers Creek soil — Pliocene(?) limestone.
Claypant
Jurassic sandstone
DRAWN BY TECHNICAL CORRESPONDENCE SCHOOL ADELAIDE S.A.
COMPILED BY R. W. JESSUP, M.Sc. SOIL CONSERVATION BRANCH DEPARTMENT OF AGRICULTURE.

Fig. 9

Origin of the Soils from Geological Parent Materials illustrated diagrammatically



depth around the salt lakes in the southern portion of the North-West where the largest areas of Coondambo soil are found.

Summing up, then, the following are the ages of the soils—Arcoona and Coober Pedy soils (Pliocene); Twins, Wilgena, Mt. Eba and Coondambo soils (post-Pleistocene); Wirraminna and Bon Bon soils (post-Pleistocene with Recent distribution of surface sands); and deep red dunes (built up during the Recent).

The distributions of the surface deposits are shown on the soil-geology plans (Figures 9 and 11).

Types of Billy

Billy (fragments of the siliceous B horizon of the Pliocene soils) is not uniform in structure. Four types found in the North-West are described below.

(1) Vitreous: This form has a vitreous appearance on freshly broken faces. It consists of quartz sandgrains and small milky and smokey quartz pebbles cemented together by silica. The surface of vitreous billy gibbers is irregular because the quartz pebbles are more resistant to weathering than the siliceous cement. Large stones of vitreous billy are iron-stained on the surface only, but the small stones may be completely iron-stained except for the quartz pebbles and sandgrains.

The proportion of quartz pebbles and sandgrains to siliceous cement varies considerably. If there are no pebbles and few sandgrains the stones have a smooth surface and a characteristic fracture, breaking up into angular pieces. Because of this quality this type of vitreous billy was commonly used by aborigines for spear heads.

(2) Black: This form of billy is heavily iron-stained right through. It consists of a mass of coarse quartz sandgrains cemented by varying proportions of ferruginous silica and yellow and red ochre.

It has no particular fracture but weathered surfaces are pitted because the sandgrains are more resistant than the cementing material. Another characteristic of the weathering of black billy is the tendency for layers to be irregularly removed from the surface of the gibbers due to the variation in the hardness of the cementing materials.

(3) Grey billy: Grey billy consists of a homogenous mass of grey-white silica which fractures irregularly. Weathering produces a fairly smooth surface.

(4) Conglomerate billy: This consists of waterworn pebbles and small stones of vitreous or grey billy and milky quartz cemented together by silica.

The individual pebbles of vitreous billy within the conglomerate gibbers have red-brown iron-stained surfaces. This iron-staining of the pebbles resulting from break-up of the siliceous B horizon formed during the first period of silicification in the Pliocene indicates that conditions must have been arid during a portion of the inter-silicification period.

The surface of conglomerate billy weathers very unevenly because the pebbles and stones that have been cemented together are more resistant to weathering than the siliceous cement.

THE SOILS

Classification

Prescott (1944) has recognised eighteen soil formations or zones in Australia, four of which are represented in north-western South Australia. These are

A. Stony and rocky areas relatively free from soil.
This formation includes ranges of the arid regions of which the Denison Range is an example.

B. Desert formations.
Prescott suggested four desert formations three of which (desert sandhills, stony deserts and desert loams) are represented in the North-West.

The "stony deserts" include a variety of unrelated soils, but in South Australia they are areas consisting of the Arcoona and Coober Pedy soils described herein. It is suggested that these soils in which the surface stone consists of billy gibbers and which are associated with a partially dissected tableland topography be called stony tableland soils. The term "desert loam" first used by Prescott (1931) is unsuitable for two reasons. In the first place the surface horizons of the soils belonging to this group range in texture from sand to clay and secondly "desert loam" soils occur in South Australia in areas with an average annual rainfall as high as 11-12″. As the "desert loams" are the earthy (in contrast to the stony and calcareous) soils of the arid regions it is proposed that they be called arid red earths. A hitherto undescribed group of calcareous soils have been designated calcareous arid soils. These are the arid members of the calcimorphic soils which end with the rendzinas and terra rossas.

The new classification for the arid soils occurring in the North-West is set out below:

Order	Sub-order	Great Soil Group	Families
Pedocals -	Arid soils -	Arid red earths - -	Coondambo Mt. Eba
		Stony tableland soils -	Coober Pedy Arcoona Twins
		Calcareous arid soils -	Wilgena Miller's Creek Bon Bon Wirraminna
		Deep red dunes - -	Wirraminna (in part) Red sandhills
		Arid ranges - - -	Denison

General Characteristics of the Soils

Soil horizons are not clearly differentiated and salinity is high except in the deep sands because the soils, as they occur in the present geological period, undergo little or no leaching.

Very shallow A horizons are a feature of all the soils except the very sandy ones as natural erosion in low rainfall areas is much greater than in higher rainfall country and the rate of soil formation is slower. Even in unstocked areas, during drought periods the soil surface is poorly protected by plant growth.

The soils range in colour from brown to red and in texture from sand to clay. They are generally poorly structured. Depending on their drainage,

they contain either heavy lime or heavy gypsum. Billy pebbles or gibbers are associated with all the soils of the North-West with the exception of the aeolian sandridges, but this is not a universal feature of arid soils.

The Soil Families

Arcoona soil

This residual Pliocene fossil soil formed from Cretaceous shale is found on the tableland country, that is, where the Pliocene land surface is least eroded. The tableland is a gently-rolling plateau which is elevated 300-350 feet above the surrounding country around its southern limits.

Depressions (crabholes) with a roughly circular or irregular shape and varying in size usually from 10-50 feet across are a feature of the soil surface. The crabholes are 4-24″ deep. Puffs (Plate XVII, Figure 4) 3-12″ higher than the shelves are formed around the lower sides of the crabholes which vary from 10-40 yards apart. The height of the puffs increases as the surface slope increases. Gently-sloping gibber-covered shelves separate the crabholes.

Water does not normally penetrate the shelf profile to a greater depth than a few inches, run-off water working its way between the gibbers on the shelf surface into the crabholes. When the crabholes higher up the slope become full of water further rain causes a flow of water to the crabholes lower down the slope. The presence of crabholes means that water only drains off the tableland after exceptionally heavy rains. The clay is easily dispersed with the result that crabhole water is always yellowish in colour immediately after a rain, but the suspended clay soon settles due to the presence of large quantities of gypsum.

Shelf areas constitute a very arid and saline environment and support only a very sparse growth of bindyis and samphire. Saltbushes (*Atriplex vesicaria* and *A. rhagodioides*) and the Composite *Ixiolaena leptolepis* are the dominant shrubs in the crabholes. Due to the heavy texture of the soil, trees are absent except along creeks and watercourses. Although Arcoona soil areas respond quickly to rain and grow more nutritious species than the sandy country they have a fairly low stock carrying capacity because plant growth is practically restricted to the crabholes.

A texture profile is not developed as clay is present on the surface, but salts are zoned according to their solubilities. Lime cannot be detected even with acid, but gypsum is always present at shallow depth and becomes heavy below. Where it is heavy the gypsum is present in bands, a soil horizon containing heavy gypsum being followed by one without gypsum. Near the soil surface it occurs in spherical clusters of white micro-crystals, but where it is heavy gypsum seen in a pit-face resembles the appearance that flour would have if dusted across the face of the pit.

The following is a typical shelf profile:

0 – ½″ brown (5 YR 6/6) [4] light clay with caked structure containing a trace of gypsum and heavy billy gibbers (boundary fairly definite).

½ – 5″ reddish-brown (5 YR 6/8) structureless clay with slight gypsum and a trace of billy gibbers (boundary very diffuse).

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[4] The figures refer to the Munsell chart of soil colours. The American interpretation of these colour standards into colour terms has not been followed.

5 –16″ red-brown (2.5 YR 5/8) massive clay with medium gypsum and a trace of billy gibbers (boundary very diffuse).

16–22″ red-brown (2.5 YR 5/8) massive clay with slight gypsum (sharp boundary).

22–48″ reddish-brown (5 YR 6/8) massive clay with heavy gypsum.

The laminated structure (an extreme case of "surface sealing") of the surface horizon of the shelf profile is interesting. Taylor (see Crocker and Skewes 1941) considers that the mechanical action of raindrops on a wet surface dispenses the surface layer of a sodium-saturated clay.

Polished brown or reddish-brown pebbles and stones (gibbers) ¼″ to 2 feet across and of irregular outline more or less cover the shelf soil surface. The bigger pieces are in the form of flat plates. The gibbers are grey-white inside and consist principally of grey and some vitreous billy. Glacial erratics of quartz and quartzite weathered out of the parent material are of rare occurrence.

A typical crabhole profile is given below:

0 – ⅛″ grey-brown (5 YR 6/6) sand with light billy gibbers (sharp boundary).

⅛ – 4″ grey-brown (7.5 YR 6/6) clay with angular cloddy structure (boundary diffuse).

4 –16″ brown (5 YR 5/6) massive clay (boundary diffuse).

16–26″ brown (5 YR 5/6) massive clay with slight gypsum (boundary diffuse).

26–36″ brown (5 YR 5/6) massive clay with heavy gypsum.

Crabholes may be gibber-free or carry a few surface stones. Large cracks form in the crabholes when they dry out.

The following is a typical puff profile:

0 – ⅛″ light reddish-brown (5 YR 7/6) sand with heavy billy gibbers (boundary definite).

⅛ – 1″ light reddish-brown (5 YR 6/6) irregular nutty structured clay with heavy gibbers (very diffuse boundary).

1 – 9″ reddish-brown (5 YR 5/6) nutty clay with medium billy gibbers (boundary sharp).

9 –17″ red-brown (2.5 YR 5/8) coarse nutty clay with light billy gibbers and slight gypsum (boundary sharp).

17–24″ red-brown (2.5 YR 5/8) structureless clay with light billy gibbers and slight gypsum (boundary sharp).

24–36″ reddish-brown (5 YR 6/8) structureless clay with heavy gypsum.

Figure 5 shows the structure of the clay and the depth at which slight and heavy gypsum appear in the shelf, crabhole and puff profiles.

Coober Pedy soil

This is a residual Pliocene fossil soil which has been more heavily truncated than the Arcoona soil. Crabholes may or may not be present, depending upon the depth of the soil. There must be at least two feet of clay overlying the parent material for crabholes to be formed. When they are present they are smaller and generally more scattered than those associated with Arcoona soil. The depressions vary from 3-40 feet across and 3-10″ in depth. Puffs are absent in flat country and smaller than those associated with Arcoona soil on sloping land.

A shallow solonized (bleached) horizon $^{1}/_{10}$″-1″ thick is usually present within an inch or two of the soil surface in the shelf profiles. Gypsum is always present,

appearing at depths of 3-24″. It may be only a trace throughout the profile but it usually becomes moderate or heavy with increasing depth. Most shelf profiles contain a trace of lime which usually appears at depths of 6-24″. The lime is generally only present in the profile for a few inches. While Coober Pedy soil normally rests on bleached shale occasional profiles are underlain by lime hardpan.

Billy gibbers $\frac{1}{8}$–12″ across more or less cover the surface of the shelves, or where crabholes are absent, the whole of the soil surface (Plate XVIII, Figure 1). Vitreous billy predominates but some grey billy is present. Rare quartz and quartzite glacial erratics from the Cretaceous shale also occur on the surface, the smaller pieces of billy and the quartzites having iron-stained surfaces. Stone in the profile varies from heavy near the surface to trace or none below.

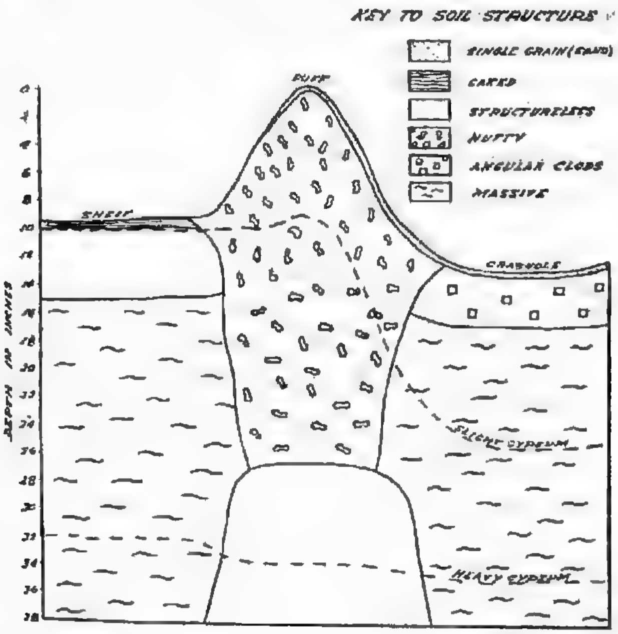

Fig. 5
Showing the structure of the clay and the depths at which slight and heavy gypsum appear in the shelf, crabhole and puff profiles of the Arcoona soil.

The following is a typical shelf profile:

0 – 1″	red-brown (2.5 YR 6/8) slightly laminated sandy loam of finely vescicular structure containing heavy billy gibbers (boundary fairly sharp but irregular).
1 – 6″	dark red (2.5 YR 3/6) angular nutty clay with a trace of billy gibbers (boundary sharp).
6 –14″	red (10 R 5/8) nutty to crumb structured clay (boundary very diffuse).
14–24″	lightish red (2.5 YR 5/8) angular nutty to crumb structured clay with a trace of billy gibbers (boundary fairly sharp).
24–32″	brownish red (2.5 YR 4/8) clay of angular blocky to crumb structure with slight lime and slight gypsum (boundary sharp).
32–40″	red (10 R 5/8) massive clay with medium gypsum (boundary sharp).

The surface horizon varies in texture from sandy loam to clay, while some profiles have brownish-red clay throughout the B horizons.

As indicated below, crabhole profiles are similar to those of the Arcoona soil except that a trace of lime is usually present:

0 –12″ brown clay.
12–20″ brown clay with a trace of lime.
20–24″ brown clay with heavy gypsum.

Coober Pedy soil areas carry saltbush (*Atriplex vesicaria*) as the dominant species and have a fairly low stock carrying capacity. Growth is practically restricted to the crabholes where they are present, while a sparse growth of saltbush occurs scattered over the whole surface where crabholes are absent.

Twins soil

This residual soil developed upon bleached Cretaceous shale is characterized by a very shallow profile without gypsum. The soil surface is littered with whitish shale fragments ⅛–3″ in size and iron-stained billy pebbles ⅛–8″ across. Vitreous billy predominates but grey billy is common. In addition rare glacial erratics of quartz and iron-stained quartzite lie on the surface. Jasper is present on the surface and through the profile where the shale has been silicified.

The soil consists of light reddish-brown to light red-brown loam, clay loam or sandy clay loam subsoil overlain by shallow red-brown sand or light reddish-brown to light red-brown sandy loam as illustrated by the following profile:

0–½″ red-brown (2·5 YR 4/6) sand with heavy bleached shale fragments and billy pebbles (boundary sharp).
½–3″ light reddish-brown (5 YR 6/4) loam to clay loam with weak crumb structure and containing slight lime (boundary diffuse).
3–5″ light red-brown (2.5 YR 6/6) clay loam with crumb structure and containing light lime and heavy bleached shale fragments (boundary fairly sharp).
5–8″ mixed brown soil, lime rubble and shale fragments. The colour of the soil fraction is light reddish-brown.

The sand horizon may be absent and even in areas where it occurs the sand is found principally around plant growth. Lime is not always as heavy as that indicated in the above profile, in fact, it is occasionally absent altogether.

Twins soil carries treeless shrub steppe vegetation dominated by bluebush (*Kochia planifolia*). The poor water-retaining capacity of the soil has resulted in widespread bush death under drought conditions even in ungrazed paddocks, with the result that living bush is practically confined to watercourses and slopes of undulations which receive run-off water. Grass and herbage only grow in large quantities on Twins soil during very good seasons.

Wilgena soil.

This residual calcareous soil has a shallow profile over lime hardpan. The surface is more or less covered with billy pebbles (Plate XVIII, Figure 2). Wilgena soil is found in country from which the Cretaceous deposits have been largely eroded away. The profiles may overlie shallow bleached Cretaceous shale or, where the shale has all weathered to soil, Jurassic sandstone. The Wilgena soil shows the influence of two parent materials. At the present

time the parent material is the lime rich layer, but the billy pebbles are a residue from the originally overlying older soil formed from shale. This older soil has also influenced the texture of the Wilgena soil.

The surface soil is reddish-brown, light reddish-brown or light red clay loam, sandy loam or rarely light clay. A sand horizon up to ½″ in thickness sometimes occurs on the surface. The subsoil is reddish-brown or light reddish-brown clay loam, sandy clay loam or light clay. Lime may be present from the surface and heavy lime (rubble or hardpan) always occurs between ½″ and 9″.

A heavy accumulation of pebbles and stones generally ⅛″ to 4″ in diameter occurs on the soil surface and in the top of the profile. On the tops of some hills the billy occurs in the form of boulders up to 12-18″ across. Vitreous billy predominates but some grey and conglomerate type billy is also found, while Cretaceous quartzite and milky quartz glacial erratics are of occasional occurrence. The smaller billy stones and the quartzite have an iron-stained red-brown surface.

The following is a typical profile:

0–½″ light red (2·5 YR 6/6) clay loam with a cakey somewhat laminated structure and containing medium lime. The surface is covered with billy pebbles and some lime flakes (boundary fairly sharp).

½–4″ light reddish-brown (5YR 6/6) clay loam containing heavy lime rubble. This overlies lime pan.

Wilgena soil supports a shrub community dominated by bluebush (*Kochia sedifolia*), but scattered trees of mulga or myall may be associated. The ground layer is dominated by bindyis (*Bassia* spp.) and grasses (principally *Enneapogon* spp.). The density of bluebush is lower on this type of soil than it is on Bon Bon soil and the growth of herbage and grass is always sparse.

Bon Bon soil

Bon Bon soil is a residual calcareous soil with a fairly shallow profile overlying lime rubble and hardpan. Morphologically it differs from Wilgena soil in three ways. The heavy lime layer generally occurs at slightly greater depth, while the soil is lighter in texture and only has a trace of stone associated with it.

Red-brown sand up to about 6″ deep overlies reddish-brown or light-brown sandy loam with light red-brown or light reddish-brown sandy clay loam or loam to clay loam below. The sandy loam horizon is absent in the shallowest profiles. Lime is always present at, or within a few inches of, the soil surface and becomes heavy (rubble and hardpan) at depths of 1–10″. Flakes and pebbles of limestone ⅛″–2″ across and very rare iron-stained billy pebbles ⅛″–2″ in diameter are scattered across the soil surface. A trace of billy pebbles usually occurs in the profiles.

A typical profile is given below:

0–2″ red-brown (2·5 YR 5/8) sand.

2–5″ light red-brown (5 YR 7/6) crumb structured sandy loam with moderate lime.

5–12″ light reddish-brown (5 YR 6/6) structureless sandy clay loam with heavy lime.

12–16″ lime hardpan.

16–20″ brown clay loam with moderate lime.

20–33″ brown clay loam with moderate lime and a trace of gypsum.

33–54″ light reddish-brown clay loam with light lime and slight gypsum.

54–72″ brown clay loam with light lime and a trace of gypsum.

Wirraminna soil

Areas with sandy soils received sand from several different sources and the sand has undergone considerable re-distribution during the arid Recent. Where

Wirraminna soil occurs in extensive sheets across the country, the sandy horizons have largely resulted from the weathering of underlying Jurassic sandstones. Throughout large areas of the North-West aeolian sandridges alternate with Bon Bon soil areas. Much of the sand in the ridges has been stripped from the intervening soils. Sand from the Pliocene soil has also contributed to the sand sheets and ridges.

As a result of the resorting of surface sands which occurred in the Recent, the sandy horizons of the Wirraminna soil vary considerably in depth. The deepest sands are found in the sandridges which grade into sandhills, while with decreasing depth of surface sand Wirraminna soil grades into Bon Bon soil.

The amount of lime and the depth at which it appears varies with the depth of sand. Trace to light lime occurs at considerable depth in the sandridges, while in those areas where the sand forms extensive sheets heavy lime is found at much shallower depth. Thus there are two variants of Wirraminna soil—a small sandridge type of aeolian origin and the soils of the extensive sand sheets.

These variations in the depth of the surface sands result in a complex vegetation pattern. On the deepest sands the dominant species are mulgas (*Acacia aneura* and *A. brachystachya*), while bluebush is absent. Where the surface sands are shallower and lime is present nearer the surface, scattered bluebushes (*Kochia sedifolia*) appear among the mulgas. Finally bluebush forms a shrub layer beneath the mulgas on the shallowest of the Wirraminna soils.

Wirraminna soil consists of up to four feet of red sand (deepest in the sandridge type) overlying clayey sand or sandy loam. The subsoil is brownish-red, reddish-brown or red (the latter in the sandridge type only) sandy clay loam. Lime is present at depths of between 8 and 50″ and except in the sandridge type becomes heavy with depth. Rubble overlies friable lime but hardpan is also common. Some of the profiles on Commonwealth Hill station have up to three feet of sand directly overlying limestone hardpan about two feet in thickness with lime rubble below. Mine shafts at the Glenloth goldfield indicate a lime-rich layer four feet in thickness overlying the Precambrian rocks with hardpan varying from 3–12″ in thickness. Billy pebbles are absent in all but the shallowest of the profiles and even then only a trace of stone occurs. Gypsum was found in a few profiles at depths of 4–5 feet but can rarely be detected.

The following profile is typical of the soils of the sand sheets:

0–18″ brownish-red sand.
18–23″ red-brown sandy loam.
23–26″ red-brown sandy clay loam.
26–30″ reddish-brown sandy clay loam with light lime.
30–32″ reddish-brown sandy clay loam with moderate lime.
32–36″ reddish-brown sandy clay loam with heavy lime.
36–45″ grey-brown sandy clay loam with heavy lime.

A typical sandridge profile is given below:

0–29″ red (10 R 4/6) sand (boundary diffuse).
29–40″ red (10 R 4/6) sand with light lime (boundary fairly diffuse).
40–41″ pale red to red (2·5 YR 6/2) and (2·5 YR 4/6) clayey coarse sand in the form of an indurated massive pan bleached through solonization (boundary sharp).
41–53″ red (10 R 4/6) massive sandy clay loam.

Miller's Creek soil

In the Miller's Creek - Billa Kalina area siliceous limestones formed during the inter-silicification period of the Pliocene are exposed. They are underlain

by Cretaceous shale which was bleached as a result of leaching during the first period of silicification, while a siliceous soil profile formed upon the limestones during the second period of silicification. Subsequent erosion removed the soil, leaving only billy pebbles on the surface of the limestone upon which a very shallow soil has subsequently formed. It is heavy-textured (clay loam or clay) and contains lime and sometimes gypsum. Pieces of siliceous limestone $\frac{1}{8}$-4″ across and occasional iron-coated billy pebbles $\frac{1}{4}$-1″ in diameter occur on the surface of the soil.

The following is a typical profile:

0–3″ brown clay with light lime.

3–6″ brown clay with light lime and a trace of gypsum.

Miller's Creek soil carries bluebushes (*Kochia planifolia* and *K. sedifolia*) and saltbush (*Atriplex vesicaria*). Its poor water-retaining capacity is reflected in the severe bush death that has occurred even with the extremely drought-resistant *Kochia sedifolia*. The growth of herbage and grass is always sparse.

Mt. Eba soil

Mt. Eba soil is developed upon Pleistocene alluvium mainly in the Mt. Eba depression and in the broad watercourses which drain into it.

The following features are typical of the soil:

Surface stone—The soil surface is more or less covered with red-brown iron-stained pebbles ranging from $\frac{1}{8}$-3″ in diameter, the majority being $\frac{1}{8}$-$\frac{1}{4}$″ in diameter (Plate XVIII, Figure 3). These pebbles consist of vitreous and grey billy and rare conglomerate billy, quartz and quartzite. The surface of the quartz pebbles is not iron-stained.

Stone through the profile—Heavy accumulations of pebbles occur in the profiles for the first few inches (sometimes up to 12″), then trace to light stone is found to the bottom of the profiles or it may be heavy again above the underlying rock.

Surface soil—The surface soil is most commonly a 3″ horizon of reddish-brown or sometimes red sandy clay loam but rarely red clay loam overlies the subsoil clay. Other profiles have shallow brownish-red sandy loam and/or $\frac{1}{4}$-$\frac{1}{2}$″ of red sand overlying the sandy clay loam.

Subsoil—Clay subsoil occurs at depths of 4-10″. The upper portion of the clay is generally reddish-brown in colour but it becomes red below. Trace to light lime is encountered between 9 and 36″. The lime usually remains trace or light but sometimes becomes moderate with increasing depth. Gypsum is usually present at depths of between 12″ and 30″. It is often moderate and rarely becomes heavy with increasing depth.

A typical profile is set out below:

0–3″ reddish-brown sandy loam.

3–6″ reddish-brown sandy clay loam.

6–9″ brownish-red clay.

9–12″ brownish-red clay with light lime.

12–21″ brownish-red clay with light lime and light gypsum.

21–34″ red clay with light lime and light gypsum.

34–42″ red clay with light lime and moderate gypsum.

42–54″ reddish-brown clay with bleached shale fragments.

This soil may carry mulgas but the characteristic feature of the vegetation is the dominance of the ground layer by bindyis (principally *Bassia divaricata*, *B. paradoxa* and *B. uniflora*).

There are two other variants of the Mt. Eba soil. The first occupies low terraces between watercourses, that is, slightly more elevated sites than the soil described above, and while similar in other respects has a light reddish-brown sandy clay loam solonized (bleached) zone ¼-2″ thick overlying the clay.

The following profile is typical of this soil type:

0–¼″ red (2·5 YR 4/8) sand (boundary definite).
¼–1″ brownish-red (2·5 YR 5/8) structureless sandy loam (boundary irregular but fairly definite).
1–3″ light reddish-brown (5 YR 6/6) somewhat domed sandy clay loam bleached horizon (boundary very irregular).
3–11″ red (10 R 4/6) clay with a nutty to angular crumb structure (boundary diffuse).
11–20″ brownish-red (2·5 YR 4/8) clay with irregular nutty to crumb structure and containing light lime and a trace of gypsum (boundary diffuse).
20–44″ brownish-red (2·5 YR 4/8) clay with irregular nutty to crumb structure and containing light lime and medium gypsum (boundary more or less abrupt).

This soil type supports a scattered growth of bluebush (*Kochia planifolia*) in addition to bindyis.

The other variant of the Mt. Eba soil occurs in the bottoms of watercourses in the Mt. Eba depression, that is, in the lowest sites. Red clay subsoil which is encountered between 0″ and 7″ may be overlain by shallow red sand or red sandy loam (or sandy clay loam) and shallow red loam (or clay loam). Lime, when it is present in the profile, occurs between 12″ and 18″ from the surface. It may become moderate or heavy in amount with increasing depth. Gypsum is encountered between 26″ and 45″. This soil type has a redder surface, deeper gypsum and lighter stone on the surface and through the profile than the other Mt. Eba soils.

A typical profile of this type is set out below:

0–3″ red sandy clay loam.
3–6″ red clay loam.
6–18″ red clay.
18–30″ red clay with a trace of lime.
30–45″ brownish-red clay with light lime.
45–48″ light reddish-brown clay with light lime and light gypsum.

Soil with this type of profile carries mulgas, dead finish (*Acacia tetragonophylla*) and bindyis.

A feature of the Mt. Eba soils, especially in areas liable to fairly frequent inundation, is the presence of "sinkholes", small crabholes of irregular shape with either sloping or vertical sides. The largest holes are about three feet across and one foot deep, but holes 6-12″ across and 6″ deep are most common. Puffs are not developed around the holes nor do shelf areas separate them. The lowest portions of small "swampy" areas, for example, may simply have half-a-dozen of these holes in them.

Coondambo soil

This arid red earth is formed from Pleistocene alluvium in low sites such as around salt lakes, in watercourses and around the lower slopes of hills and tablelands. The underlying rock occurs at depths of 6″ to 4 feet.

The following features are characteristic of Coondambo soil:

Surface soil—The surface horizon consists of red sand ½–2″ in thickness except in watercourses where it is usually deeper. This is underlain by either light red-brown to red-brown loamy sand, sandy loam, sandy clay loam or rarely loam or clay loam.

Subsoil—Red clay which often becomes sandy or gritty with increasing depth occurs between 3″ and 15″ from the surface. A very shallow solonized (bleached) horizon frequently overlies the red clay. Trace to light lime is found at depths of 14–30″ and may increase to medium at greater depths. Trace to light gypsum which often becomes moderate with increased depth appears at 12–40″.

Stone—Stone is generally absent but trace to light billy pebbles usually not exceeding 1″ in diameter but rarely 4–5″ across may be present.

The following is a typical profile:

0–½″ red (2·5 YR 4/6) coarse sand (boundary sharp).

½–3″ red-brown (5 YR 4/6) massive loamy sand (boundary sharp but irregular).

3–4½″ light red-brown (5 YR 6/6) loamy sand. This bleached horizon has a slightly domed structure (boundary sharp).

4½–15″ red (2·5 YR 4/6) massive light clay (boundary fairly sharp).

15–20″ dark red (10 R 4/4) massive sandy light clay with slight gypsum and light lime (boundary fairly sharp).

20–31″ red (2·5 YR 5/8) crumb structured sandy light clay with slight gypsum and light lime (boundary fairly sharp).

31–45″ red (2·5 YR 4/8) crumb structured sandy light clay with medium lime and trace of gypsum.

Very shallow soil profiles of the Coondambo type which are superimposed upon Bon Bon or Coober Pedy soil occur on flats between sandhills in some localities. These Coondambo soils have originated in the same way as claypans, that is, by downward percolation through the sandhills and subsequent drainage on to the flats of water containing clay in suspension. This downward percolation and outward movement of water from the base of the dunes probably occurred during the moist period of the Recent referred to in the chapter on geology. A patchy cover of sand over the clay has resulted both from washing and blowing of sand from the foot of the dunes.

Coondambo soil areas carry a very dense growth of saltbush (*Atriplex vesicaria*) and bluebush (*Kochia planifolia*) and have a greater stock carrying capacity than any other type of country in the North-West.

Deep red dunes

The sandhills are aeolian formations built up during the Recent arid period. Under subsequent moister conditions the dunes were colonized by mulgas (*Acacia linophylla* and *A. ramulosa*) in the south and sandhill canegrass (*Zygochloa paradoxa*) in the Anna Creek - Oodnadatta area, so that they are now all fixed dunes.

The source of the sand, nature of the interdune areas and the trend of the dunes have already been discussed. Red sand (10 R 4/6) to a depth of more than 9 feet (the maximum depth of boring) is characteristic of the crests of the dunes. Down the slopes variable depths of red sand (depending upon the distance from the crest) overlie red clayey sand. This clayey sand horizon has resulted from downward persolation of water containing suspended clay.

The distribution of all the soils is shown in the soil plans (fig. 9 and 11).

Erosion

Natural erosion of soils carrying native vegetation in arid areas is considerably greater than in higher rainfall areas. Most erosion occurs during drought years when the soil surface is not perfectly protected even where the original bush cover is not depleted through stocking. Thus mounds of soil always accumulate around the bushes even in unstocked country. Partly as a result of this natural erosion, all the arid soils except those consisting of sand accumulations have shallow A horizons.

No measurements of soil loss caused by accelerated erosion have been made, as estimates on the basis of profile comparisons are considered impracticable on account of the natural variations in depth of the A horizons. However, it is the general impression that accelerated erosion has been insignificant throughout most of the North-West but moderate in a few localities.

From the point of view of erodability the soils may be divided into three groups: (1) those with a surface mantle of stones; (2) soils with sandy A horizons; and (3) Miller's Creek soil which is heavy-textured and has little surface stone. Included in the first group of soils are the Mount Eba, Coober Pedy, Arcoona, Wilgena and Twins types. The surface cover of stones helps to protect the soils from wind erosion, especially in the case of Arcoona and Coober Pedy soils where the stones are large and the cover is more complete. While most of the North-West is not prone to water erosion, the Arcoona and Coober Pedy soils would be if it were not for the surface stone and the crabholes on account of the topography with which they are associated. Of the five stony soils Twins soil has suffered greatest erosion.

With the exception of Coondambo soil, the soils with sandy A horizons (Wirraminna, Bon Bon, Coondambo and deep red dune soils) carry a fairly dense growth of trees and are therefore well protected from wind action. However, tree death is widespread and there is little regeneration, so that eventually a severe erosion problem can be expected on these sandy soils.

Coondambo soil with its very shallow sandy horizons overlying clay subsoil is liable to the most serious damage by wind erosion. Moderate sheet erosion has occurred in some areas but most Coondambo soil is located around saltlakes where it is difficult to obtain underground supplies of stock water, with the result that these areas are largely ungrazed. Soil loss from Miller's Creek soil areas has been moderate because widespread bush death has occurred on account of the poor water-retaining capacity of the soil.

ANALYTICAL DATA ON THE SOILS

oil family	ARCOONA (SHELF)					ARCOONA (CRABHOLE)					ARCOONA (PUFF)				
ocality	Mount Eba Station					Mount Eba Station					Mount Eba Station				
oil number	15405	15406	15407	15408	15409	15415	15416	15417	15418	15419	15410	15411	15412	15413	15414
epth (inches)	0–½	½–5	5–16	16–22	22–36	½–4	4–8	8–16	16–26	26–36	½–1	1–9	9–17	17–24	24–28
eaction pH	6·82	6·97	7·26	7·44	7·28	7·99	8·21	7·68	7·00	7·30	9·22	9·12	9·56	8·46	8·08
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
ravel in original sample	22	10	8	1	0	4	0	0	—	—	34	30	16	4	0
alcium carbonate	—	—	—	—	—	<0·01	—	—	—	—	0·01	—	0·07	—	<0·01
oarse sand	18½	13½	—	—	12½	15¾	—	12¼	—	—	18	—	12¾	—	17¾
ine sand	39½	38¼	—	—	26½	33½	—	30¾	—	—	41¾	—	34¾	—	35¾
ilt	18¾	23¾	—	—	3	5½	—	5½	—	—	14½	—	16½	—	10¼
lay	18¾	17¾	—	—	47¼	42½	—	48¼	—	—	24½	—	34	—	33
oss on acid treatment	2·4	3·7	—	—	11·7	—	—	2·3	—	—	—	—	—	—	—
oss on ignition	4·0	4·9	5·3	4·1	4·9	4·1	4·2	4·3	4·5	4·3	3·7	4·1	3·9	3·9	3·6
rganic carbon C	0·21	—	—	—	—	—	—	—	—	—	—	—	—	—	—
itrogen N	0·033	—	—	—	—	—	—	—	—	—	—	—	—	—	—
hosphoric acid P_2O_5	0·101	—	—	—	—	—	—	—	—	—	—	—	—	—	—
otal soluble salts	1·60	2·26	2·46	2·39	3·02	0·045	0·195	1·04	2·42	2·22	0·061	0·032	0·142	1·56	1·94
hlorides as NaCl	1·24	1·80	1·84	1·93	1·77	0·021	0·103	0·645	1·02	0·878	0·025	0·017	0·025	1·17	1·14
xchangeable cations	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%
Calcium Ca	—	—	—	—	—	13·9	—	—	—	—	10·7	—	—	—	—
Magnesium Mg	—	—	—	—	—	7·0	—	—	—	—	5·7	—	—	—	—
Potassium K	—	—	—	—	—	1·91	—	—	—	—	3·34	—	—	—	—
Sodium Na	—	—	—	—	—	4·71	—	—	—	—	6·36	—	—	—	—
Total metal ions	—	—	—	—	—	27·5	—	—	—	—	26·1	—	—	—	—
oisture in air dry sample	4·3	5·9	7·0	7·2	9·0	5·9	6·8	7·0	8·3	8·9	4·0	6·3	6·3	6·8	6·7

Soil family	COOBER PEDY (SHELF)						TWINS				WILGENA	
Locality	Mt. Eba Station						Mt. Eba Station				Bon Bon Station	
Soil number	15420	15421	15422	15423	15424	15425	15426	15427	15428	15429	15434	15435
Depth (inches)	0–1	1–6	6–14	14–24	24–32	32–41	0–½	½–2½	2½–5	5–10	0–½	½–4
Reaction pH	7·48	7·60	7·21	7·11	8·09	8·00	8·78	9·15	9·21	8·77	8·99	9·17
Gravel in original sample	28	3	1	—	—	—	31	5	20	51	33	40
Calcium carbonate	—	—	—	—	0,09	—	0·27	0·12	0·68	34·8	5·1	9·3
Coarse sand	34	15¾	—	—	19½	—	54	44½	44¼	25	32¼	41
Fine sand	43½	20¾	—	—	19½	—	31¾	28½	26¼	17½	33¼	26
Silt	13¾	6	—	—	3	—	4½	8	9	8	9½	7½
Clay	7	53¾	—	—	53½	—	8	15¾	18	14½	15½	14
Loss on acid treatment	—	—	—	—	—	—	—	1·3	—	—	7·1	—
Loss on ignition	2·1	5·8	5·7	5·8	5·8	5·0	2·2	3·2	3·6	15·2	5·7	7·4
Organic carbon C	0·21	0·29	—	—	—	—	—	0·35	—	—	—	—
Nitrogen N	0·028	0.043	—	—	—	—	—	0·035	—	—	—	—
Phosphoric acid P_2O_5	0·040	0·054	—	—	—	—	—	0·035	—	—	0·054	—
Total soluble salts	0·073	0·534	0·914	1·88	1·88	2·50	0·037	0·031	0·040	0·226	0·033	0·034
Chlorides as NaCl	0·033	0·348	0·648	1·45	1·55	1·29	0·011	0·009	0·010	0·126	0·006	0·005
Exchangeable cations	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%
Calcium Ca	—	19·5	—	—	—	—	—	—	—	—	—	—
Magnesium Mg	—	7·0	—	—	—	—	—	—	—	—	—	—
Potassium K	—	2·06	—	—	—	—	—	—	0·52	—	—	1·18
Sodium Na	—	4·59	—	—	—	—	—	—	0·72	—	—	0·20
Total metal ions	—	33·2	—	—	—	—	—	—	—	—	—	—
Moisture in air dry sample	1·6	7·4	9·3	10·5	9·7	10·0	1·3	2·6	3·1	3·4	2·1	2·0

Soil Family	MT. EBA						WIRRAMINNA				
Locality	Mt. Eba Station						Bon Bon Station				
Soil number	15399	15400	15401	15402	15403	15404	15436	15437	15438	15439	15440
Depth (inches)	0–¼	¼–1	1–3	3–11	11–20	20–44	0–3	3–29	29–40	40–41	41–52
Reaction pH	7·93	8·64	8·95	8·98	9·36	8·19	7·35	7·08	7·95	8·21	8·41
	%	%	%	%	%	%	%	%	%	%	%
Gravel in original sample	35	25	7	4	6	8	0	0	1	2	8
Calcium carbonate	<0·01	<0·01	<0·01	<0·01	—	—	—	—	0·01	<0·01	<0·01
Coarse sand	66	51¼	43¾	—	—	—	61¾	63¾	64½	62½	59¼
Fine sand	28¾	31	27¼	—	—	—	31½	28½	29¼	29¼	22½
Silt	2½	11½	15½	—	—	—	4½	4	4	5¾	3
Clay	2½	5¾	11	—	—	—	2¼	2¾	2½	1¾	12½
Loss on ignition	1·4	2·4	2·9	6·3	6·6	6·0	1·4	1·3	1·3	1·2	2·1
Organic carbon C	0·16	0·21	—	—	—	—	0·14	—	—	—	—
Nitrogen N	—	0·026	—	—	—	—	0·016	—	—	—	—
Phosphoric acid P_2O_5	—	0·055	—	—	—	—	0·023	—	—	—	—
Total soluble salts	0·015	0·018	0·010	0·032	0·198	0·994	0·006	0·004	0·007	0·007	0·015
Chlorides as NaCl	0·003	0·006	0·006	0·013	0·079	0·393	0·001	nil	0·001	0·002	0·007
Exchangeable cations	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%
Calcium Ca	1·6	3·1	3·7	13·4	—	—	—	—	—	1·9	—
Magnesium Mg	1·4	2·7	3·2	10·2	—	—	—	—	—	1·1	—
Potassium K	0·46	1·02	1·09	3·02	—	—	—	—	—	0·38	—
Sodium Na	0·15	0·69	1·37	5·29	—	—	—	—	—	0·13	—
Total metal ions	3·6	7·5	9·4	31·9	—	—	—	—	—	3·5	—
Moisture in air dry sample	0·6	1·4	2·0	8·1	7·6	7·8	0·5	0·6	0·7	0·7	1·9

Soil family	COONDAMBO							BON BON			
Locality	Wilgena Station							Bon Bon Station			
Soil number	15441	15442	15443	15444	15445	15446	15447	15430	15431	15432	15433
Depth (inches)	0–½	½–3	3–4½	4½–15	15–20	20–31	31–45	0–¼	¼–1½	1½–4½	lime pan
Reaction pH	8·40	8·65	8·34	7·72	8·49	8·51	8·66	8·76	9·12	9·16	9·15
	%	%	%	%	%	%	%	%	%	%	%
Gravel in original sample	3	2	2	1	3	2	7	18	15	23	39
Calcium carbonate	<0·01	<0·01	—	—	3·0	—	5·8	—	16·8	28·4	39·5
Coarse sand	57¼	53¼	—	38	26¼	—	31¼	—	34¾	30	24
Fine sand	33	35½	—	28	30½	—	29¼	—	27¾	21	19¾
Silt	4¾	7¼	—	10	18¼	—	8½	—	6¾	5	6½
Clay	3	2¾	—	22	19½	—	22½	—	12¼	12½	11
Loss on acid treatment	—	—	—	—	3·8	—	7·3	—	—	—	—
Loss on ignition	1·4	1·5	1·6	3·2	5·5	5·5	5·5	6·2	10·8	12·0	12·5
Organic carbon C	—	0·09	—	—	—	—	—	—	0·55	—	—
Nitrogen N	0·021	—	—	—	—	—	—	—	0·039	—	—
Phosphoric acid P_2O_5	—	0·028	—	—	—	—	—	—	—	—	—
Total soluble salts	0·013	0·010	0·031	0·311	0·921	0·932	0·789	0·031	0·032	0·033	0·039
Chlorides as NaCl	0·003	0·005	0·018	0·204	0·683	0·660	0·547	0·005	0·004	0·004	0·004
Exchangeable cations	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%	m.e.%
Calcium Ca	—	2·2	—	5·4	—	—	—	—	—	—	—
Magnesium Mg	—	1·8	—	4·5	—	—	—	—	—	—	—
Potassium K	—	0·68	—	0·97	—	—	—	—	—	0·58	—
Sodium Na	—	0·40	—	3·29	—	—	—	—	—	0·23	—
Total metal ions	—	5·1	—	14·2	—	—	—	—	—	—	—
Moisture in air dry sample	0·6	0·8	1·4	3·9	6·7	5·4	4·1	0·8	1·6	1·8	2·6

Except for the Bon Bon, Twins, Wilgena and Wirraminna families the soils show chemical data consistent with marked solonization. The reaction is alkaline in all except the top of the Arcoona shelf profile (pH 6·8). The highest value recorded was a pH of 9·6 in the Arcoona puff. A high total soluble salt content (1·60%) in the surface ½" of the Arcoona shelf profile indicates a complete lack of leaching and hence a very arid environment for plant growth. This aridity combined with the high salt content is responsible for the sparse occurrence of plants on the shelves (Crocker and Skewes 1941).

Phosphates are low to moderate, ranging from ·02% - ·05% except in the Arcoona shelf (·10%) where the phosphate content is fairly high by comparison with other Australian soils. Figures for organic carbon (all less than ·6%) indicate a very low organic matter content. Nitrogen is correspondingly low but the carbon: nitrogen ratio is generally about 9: 1, which is a favourable figure.

THE VEGETATION

Classification of the Plant Communities

In this survey the basic unit used in the classification of the vegetation is the plant association as defined by Crocker and Wood (1947), and wherever possible this unit has also been used in the vegetation mapping (Figures 8 and 10). The associations and the factors determining their distribution are set out in Table X. However, over large areas certain of the associations are constantly grouped together and it has not been possible to map the individual associations on the scale used in the survey (two miles to the inch). In any case, from a practical viewpoint these association groups form definite land types.

Table X

Association	Soil	Geology	Annual rainfall	Formation
Acacia linophylla – A. ramulosa	deep red dunes	Recent sand-hills	5½–7½"	arid woodland
Zygochloa paradoxa	deep red dunes	Recent sand-hills	<5½"	desert sclerophyllous grassland
Acacia aneura – A. brachystachya	Wirraminna, Bon Bon and Wilgena	Recent sand and clay	4½–7½"	arid woodland to shrub-arid woodland
A. sowdenii – Kochia sedifolia	Bon Bon and Wilgena	Recent sand and clay	5½–9"	shrub-arid woodland
Atriplex vesicaria – Bassia spp.	Coober Pedy	Cretaceous shale	5–9"	shrub steppe
Atriplex vesicaria – Kochia planifolia	Coondambo	Pleistocene alluvium	5–9"	shrub steppe
K. sedifolia	Bon Bon and Wilgena	Recent sand and clay	5–9"	shrub steppe
Acacia aneura – A. brachystachya – A. tetragonophylla	Mt. Eba	Pleistocene alluvium	5½"–6"	arid woodland
K. planifolia – Bassia spp.	Mt. Eba	Pleistocene alluvium	5½"–6"	shrub steppe
Eremophila freelingii – Acacia aneura – A. brachystachya	Arid ranges	Precambrian	—	arid hill woodland
Atriplex vesicaria – Ixiolaena leptolepis	Arcoona	Cretaceous shale	5½–9"	shrub steppe
A. rhagodioides	Arcoona	Cretaceous shale	<5½"	shrub steppe
Kochia planifolia	Twins	Cretaceous shale	5–7"	shrub steppe
Kochia planifolia – Atriplex vesicaria – K. sedifolia	Miller's Creek	Pliocene (?) Limestone	5½"	shrub steppe

In past ecological studies in South Australia the "edaphic complex" (see Crocker and Wood, 1947) has been widely used as a mapping unit but it has been applied to two different types of complexes. It has been used in the mapping of areas where two or more floristically unrelated plant associations are randomly

ASSOCIATION COMPLEXES DUE TO THE PRESENCE OF SANDHILLS

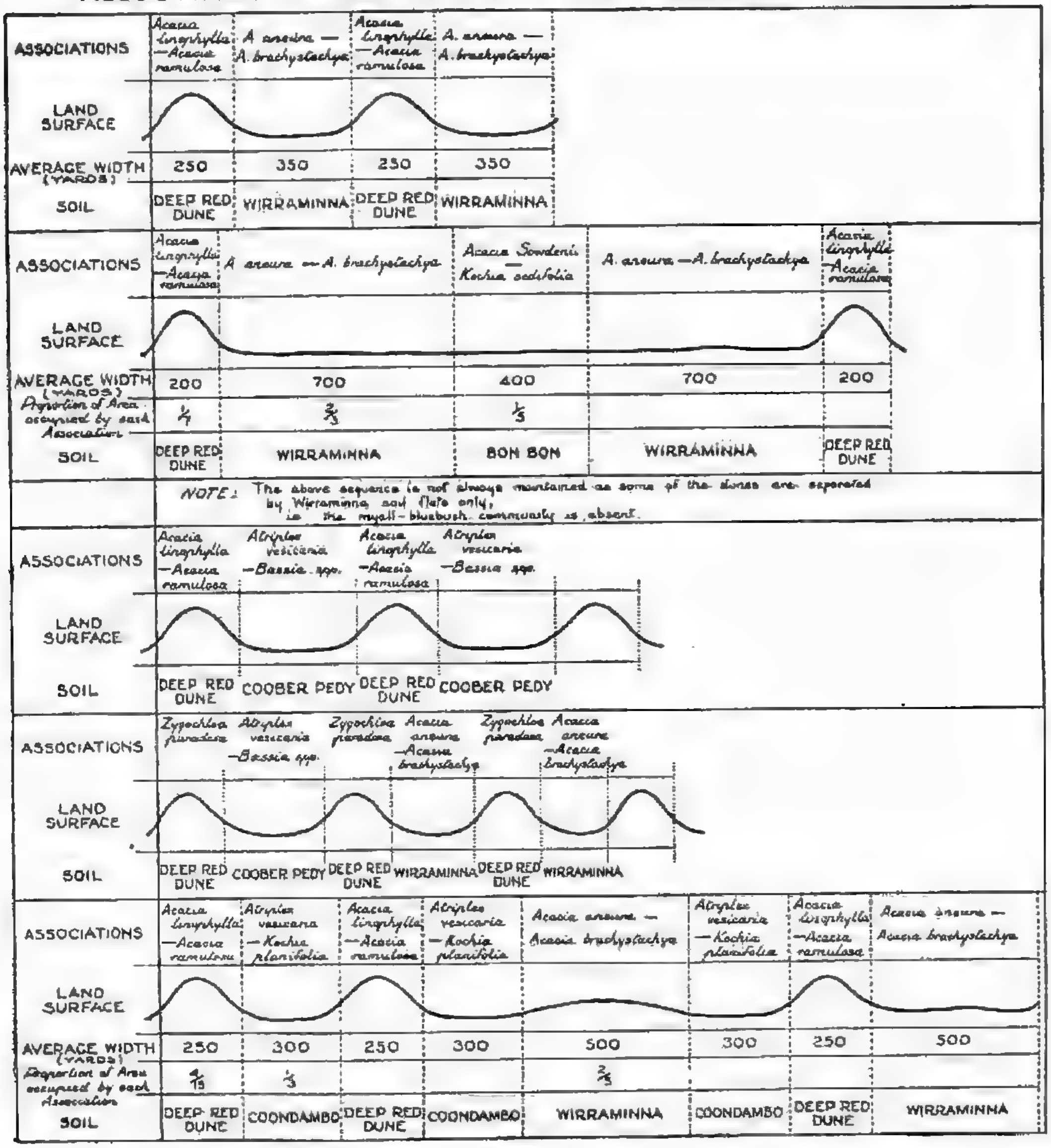

Fig. 6

or regularly distributed on different soils, for example, the *Zygochloa paradoxa*–*Triodia basedowii* edaphic complex of the Simpson Desert (Crocker 1946) where the *Z. paradoxa* association occurs on the sandhills and the *T. basedowii* association occurs on the sandy flats between the dunes.

Secondly, the edaphic complex has been used, for example by Specht and Perry (1948) in the "stringybark edaphic complex" of the Adelaide Hills, in the

sense defined by Crocker and Wood who state: ". . . . We have used one feature of the habitat, namely, allied soils, associated with related floristic composition of species as a basis for classification. Within definite climatic limits, associations on nearly related soil types and with related floristic composition are grouped together as an edaphic complex."

If the term "edaphic complex" is to have any significance it is obvious that it should only be used in the sense of the definition, and that a new term must be introduced into ecological nomenclature for the other type of complex. The "association complex" is a group of two or more associations which occur on unrelated soils and which show random distribution within an area. Each individual association invariably occurs on the one soil so that within the complex

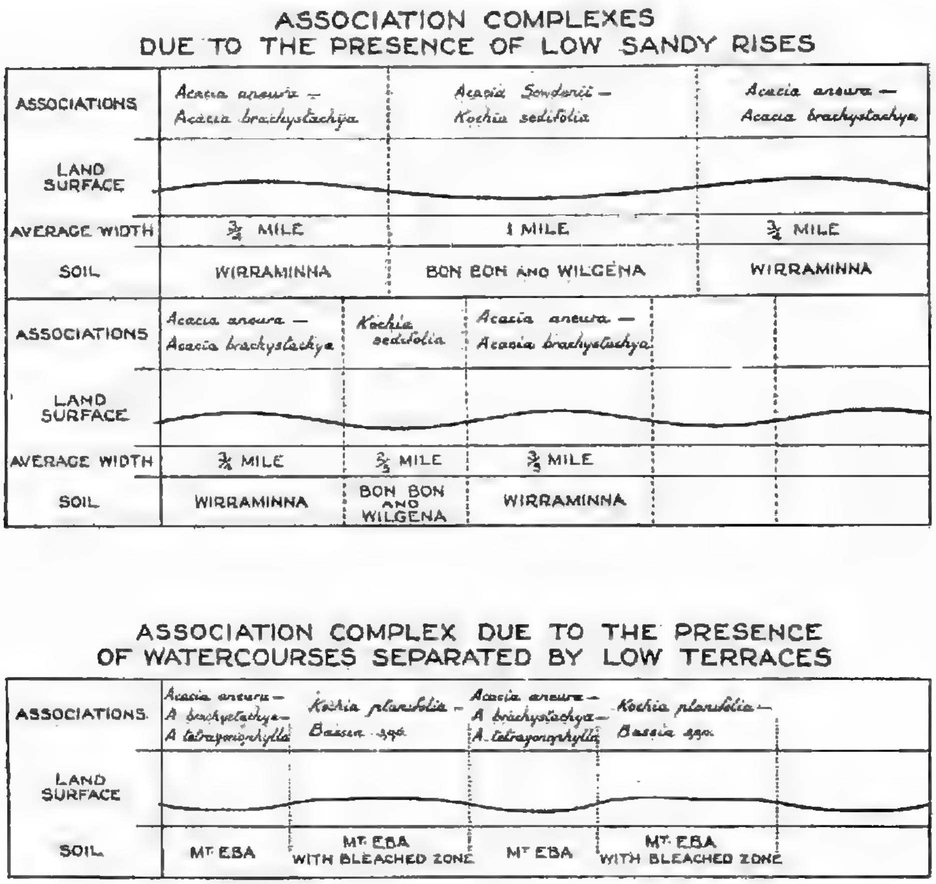

Fig. 7

each association becomes a soil indicator. The *Eucalyptus oleosa – E. dumosa* association which is found on the brown solonized soil flats and the *E. angulosa – Melaleuca uncinata* association which occurs on the solonetz sandhills in the Murray Mallee (Jessup 1946) form an association complex. In the North-West a particular expression of the association complex occurs as a consequence of the regular and parallel spacing of the sand dunes. With this type of topography, when the contours are traversed at right angles there is a regular repetition of associations. For convenience this particular expression of the association complex has been styled an association repetition on the vegetation map.

The association complexes occurring in the North-West are set out in fig. 6 and 7.

Only one of these complexes requires further discussion. The *Zygochloa paradoxa — Acacia aneura – A. brachystachya — Atriplex vesicaria – Bassia* spp. association complex occurs in the Lake Eyre region where sandhills are superimposed upon tableland. The flats between the dunes are sandy where they are close together or clayey (Coober Pedy soil) where the dunes are scattered. *Acacia linophylla* and *A. ramulosa* are absent, their place on the dunes being taken by canegrass (*Z. paradoxa*). In contrast to the adjacent Simpson Desert (Crocker 1946), spinifex is absent from the sandy interdune soils which carry a modified mulga community. *Atriplex vesicaria – Bassia* spp. association occurs where the flats separating the sandhills have clay soils.

The plant associations may be classified into five formations.

Shrub-steppe formation

This includes treeless areas dominated by shrub species belonging to the genera *Atriplex* (*A. vesicaria* and *A. rhagodioides*) and *Kochia* (*K. planifolia* and *K. sedifolia*), small shrubs which grow to a height of 12-36". Trees are absent because of the comparative heavy texture of the surface soils.

The dominant shrubs vary greatly in their density of growth according to species, associated soil and rainfall. In ungrazed stands of bladder saltbush (*Atriplex vesicaria*) and low bluebush (*Kochia planifolia*) there may be as many as 170 to 180 bushes on 2/33 acre (see quantative estimates). On the other hand, stands of bluebush (*Kochia sedifolia*) may have a density as low as 20 to 25 bushes on 2/33 acre.

During drought times the ground between the shrubs is devoid of growth but in good seasons may, depending upon the soil and also upon the density of the shrubs, be almost completely covered with herbage and grass. Where the growth of bush is very dense competition is so severe that even in good seasons little herbage or grass appears between the bushes.

Arid woodland formation

Trees (*Acacia* spp.) form a woodland of variable density on the lighter textured soils and normally vary from 20 to 50 yards apart. In previous literature the *Acacia* woodland country has been referred to as a scrub formation but this term is misleading when applied to country in which trees are frequently very scattered and there is a scarcity of undershrubs. Grasses, of which *Aristida* spp. (*A. arenaria* and *A. browniana*) and *Enneapogon* spp. (*E. polyphyllus* and *E. avenaceus*) are most widespread, are most prominent in the ground layer especially after summer rains. *Bassia uniflora* is common following winter rains.

Shrub-arid woodland formation

This includes areas where an understorey of shrubs occurs beneath the trees. The formation grades into the shrub-steppe formation on the one hand and the arid woodland formation on the other according to the density of the trees and shrubs.

Arid hill woodland formation

In previous literature the arid hill communities have been called scrubs but are better regarded as woodlands. The formation is represented in the North-West by the community on the Denison Range.

Desert sclerophyllous grassland formation

The dominant species on the sandhills of the desert or near desert areas is the sclerophyllous grass *Zygochloa paradoxa* (sandhill canegrass). Herbaceous grasses are the principal associated species.

THE PALATABILITY OF THE SPECIES

The plants occurring in the communities of the North-West have been assigned to five palatability groups: those with a palatability rating of 1 are very palatable, 2 are quite palatable, 3 are moderately palatable, 4 are slightly palatable and 5 are unpalatable. The palatabilities were largely assessed from observations of selectivity of grazing around watering points.

The palatability of any plant to stock depends upon a number of factors, which are determined by both the grazing animal and the plant species. Palatability ratings given here are the preferences of mature merino sheep. The most important factors influencing the palatability of any plant species are its growth stage and the plants with which it is associated. The growth stage is particularly important in the case of species which produce spiny fruits, for example, the Bassias, and which are therefore more palatable when young than when mature. The palatability ratings given here are an average for the whole of the life cycle. The importance of the collection of plants available to the grazing animal is illustrated by the fact that even some of the unpalatable species (palatability 5) like *Kochia pyramidata* are grazed under drought conditions when nothing else is available, in fact under extreme conditions sheep will eat dry sticks and twigs.

Palatability ratings have been given to about 170 species. Shrubs and trees with a palatability of 1 are few in number. Very palatable trees are not destroyed by stock because a portion of their foliage is out of reach, but the very palatable shrubs like *Cassia sturtii* and *Eremophila latrobei* have been considerably depleted. There are more very palatable herbaceous species (grasses being prominent) than trees and shrubs and many of them, for example *Erodium cygnorum, Clianthus speciosus, Convolvulus erubescens, Trichinium exaltatum* and *Eragrostis dielsii* are suppressed by grazing. Others like *Stipa nitida* remain of common occurrence because they are prolific seeders.

Again there are very few shrubs and trees with a palatability of 2, but this group includes the widespread *Kochia planifolia* and *Atriplex vesicaria,* species which are destroyed by heavy stocking. Herbaceous species with a palatability of 2, among which grasses are prominent, are also few in number and most of them are suppressed in heavily grazed country. More plants occur in group 3 than in either groups 1 or 2, and herbaceous species are more numerous than shrubs and trees. Moderately palatable species are not often suppressed except under conditions of very heavy stocking.

Slightly palatable species (palatability 4) are not suppressed by grazing and more plants fall into this group than in either groups 1, 2, 3, or 5. The majority of the shrubs and herbaceous species do not spread in heavily grazed country but they do persist. There are exceptions however like the free-seeding *Bassia paradoxa* and *Atriplex halimoides* which spread on certain soil types. Genera represented by the largest number of slightly palatable species are *Zygophyllum* with *Z. crenatum, Z. ammophilum, Z. iodiocarpum,* and *Z. compressum* and *Eremophila* with *E. scoparia, E. duttonii, E. serrulata, E. alternifolia, E. oppositifolia* and *E. maculata.*

Group 5 (plants of no value) contains about the same number of species as group 3 but shrubs are more numerous than herbaceous species. Some of the free-seeding species like *Kochia triptera* var. *erioclada, K. pyramidata* and *Bassia*

divaricata spread where competition with more palatable species has been reduced through grazing.

The palatability ratings of species of *Bassia, Kochia, Atriplex, Acacia* and grasses occurring in the North-West are set out in Table XI.

The plant associations

Acacia aneura – A. brachystachya association ("mulga country").

The dominant species of this community are *A. aneura* and *A. brachystachya,* small trees which grow to a height of 16-24 feet. These species cannot be distinguished on vegetative characters alone. Although *A. aneura* most commonly has one main trunk and *A. brachystachya* two or three, the reverse is frequently found. Black (1929) gives the length of the phyllodia in *A. aneura* as 3-7 centimetres but lengths of up to 10 centimetres are not uncommon, thus overlapping the range for *A. brachystachya* which is 5-18 centimetres. However, the pods of the two species are fairly easily distinguished and in August - September of 1946, when their distributions were determined by reconnaissance survey, the two species were both fruiting prolifically. The community is found on sandy soils of the Wirraminna type, calcareous Bon Bon soil and occasionally the heavier textured calcareous Wilgena soil.

On the deepest sands mulgas form a woodland of variable density (Plate XVIII, Figure 4 and Plate XIX, Figure 1). They become more scattered on Bon Bon soil and sparse (or more usually absent) on Wilgena soil. The understorey also varies greatly. Where more than three feet of sand overlies lime rubble or hardpan bladder saltbush and bluebush are both absent. Bladder saltbush appears where two to three feet of sand overlies heavy lime, while bluebush will only grow where less than two feet of sand overlies the lime. The mulga community therefore varies from a fairly dense woodland with a grass layer beneath the trees to a shrub-woodland with scattered trees and an understorey of shrubs. All gradations occur between these two extremes and because the surface sands were redistributed during the Recent the pattern is very complex.

The following are the chief floristic characteristics of the association on the three soils:

1. *Mulga on Wirraminna (sandy) soil*

The mulgas usually form a fairly dense woodland. Bluebush is absent from the deepest sands but forms an understorey where the surface sands are shallower. Prior to stocking bladder saltbush was common, but the ecotype associated with sandy soil is easily destroyed by grazing, so that little remains in stocked country. The ground between trees and shrubs is dominated by mulga grass (*Aristida arenaria*), black heads (*Enneapogon polyphyllus* and *E. avenaceus*) and bindyi (*Bassia uniflora*), which form a complete ground cover in favourable years. *Danthonia bipartita* and *Eragrostis eriopoda* are also prominent on sandridges with the above herbaceous species.

A wide variety of shrubs and herbaceous species are associated, the commonest of which are *Kochia georgei* (erect form), Australian boxthorn (*Lycium australe*), tomato bush (*Enchylaena tomentosa*), *Sida virgata,* firebush (*Kochia triptera* var. *erioclada*), bundy bush (*Cassia eremophila* var. *platypoda*), cat tail (*Trichinium alopecuriodeum*) and buck bush (*Salsola kali*). Of these species *K. georgei,* tomato bush, bundy bush and cat tail are of little value to the grazier. Australian boxthorn, which sheds its leaves under drought conditions, and *Sida virgata* are moderately palatable. Firebush is a free-seeding rapid growing species which colonizes overgrazed country where competition with other species

VEGETATION PLAN.

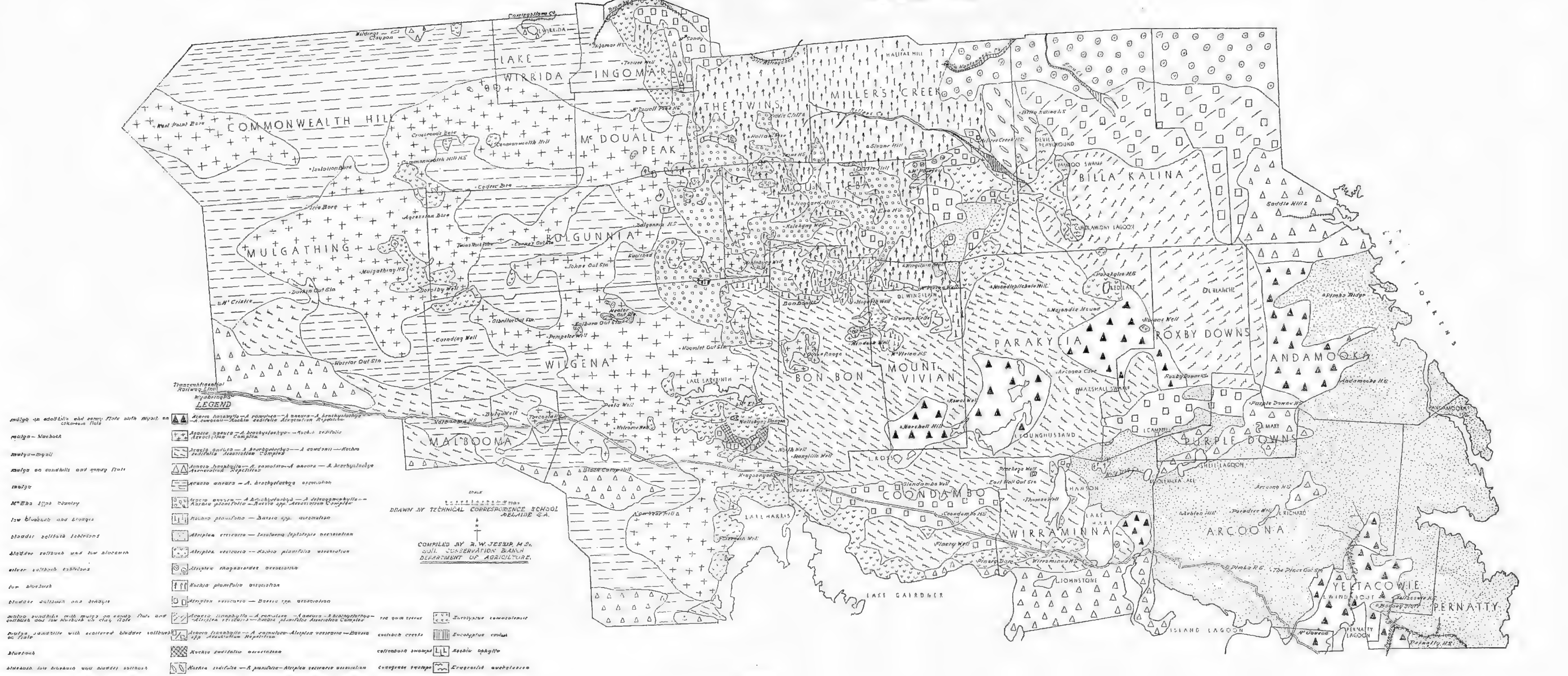

Fig. 3

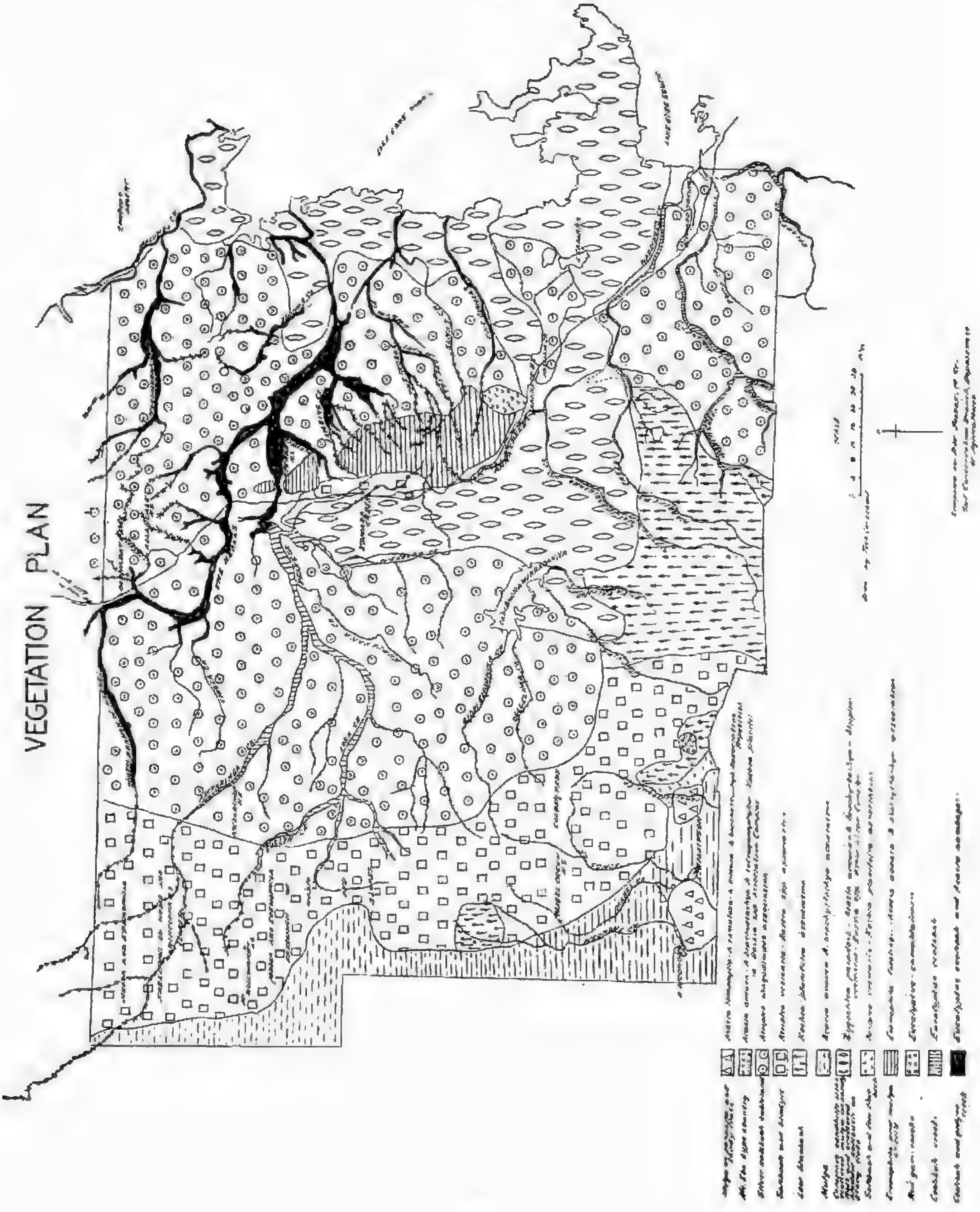

Fig. 10

TABLE XI Showing the palatability ratings of certain species

Palatability	1	2	3	4	5
Bassia -	uniflora	patenticuspis eriacantha	sclerolaenoides decurrens lanicuspis obliquicuspis ventricosa	paradoxa brachyptera	divaricata bicornis tricuspis
Kochia -	—	planifolia eriantha	sedifolia	aphylla tomentosa var. appressa	pyramidata triptera var. erioclada triptera var. pentaptera
Atriplex -	—	vesicaria	spongiosa	halimoides	quinii, rhagodioides, velutinellum
Acacia -	aneura brachystachya	—	victoriae oswaldii	rigens linophylla ramulosa sowdenii tetragonophylla kempeana	ligulata burkittii
Grasses -	Eriochloa longiflora Eragrostis dielsii Sporobolus actinocladus Eulalia fulva Danthonia semi-annularis Stipa nitida	Paspalidium sp. Enneapogon E. avenaceus E. polyphyllus Dactyloctenium radulans Iseilema vaginiflorum Eragrostis setifolia	Triraphis mollis Chloris truncata C. acicularis Eragrostis falcata Astrebla pectinata Panicum decompositum Plagiosetum refractum Aristida anthox-anthoides A. arenaria Enneapogon caerulescens E. cylindricus	Eragrostis australasica Aristida browniana Eragrostis eriopoda Danthonia bipartita	—

has been reduced. It is unpalatable. Bundy bush colonizes sandy mulga country where the trees have been destroyed by firing. Tomato bush is always found beneath tree canopies.

2. *Mulga on Bon Bon soil*

The mulgas are more scattered and the herbaceous growth is sparser as the sandy A horizons of the soils become shallower. Bluebush forms an understorey beneath the trees. The only associated shrubs of common occurrence are bird's-eye Cassia (*Cassia sturtii*) and *Acacia kempeana*. *Sida virgata* and the small-leafed form of *Chenopodium nitrariaceum* are fairly common. Bladder saltbush was once common but has largely been destroyed by grazing.

The chief herbaceous species are bindyi (*Bassia obliquicuspis*), mulga grass (*Aristida arenaria*), black heads (*Enneapogon cylindricus*, *E. caerulescens*, *E. polyphyllus* and *E. avenaceus*), while *Bassia uniflora*, *B. sclerolaenoides*, geranium (*Erodium cygnorum*) and *Zygophyllum prismatothecum* are fairly common. Of these species *B. obliquicuspis*, *B. sclerolaenoides*, *Enneapogon cylindricus* and *E. caerulescens* are most prominent on the shallowest of the Bon Bon soils. Where the surface sands are slightly deeper mulga grass, *E. polyphyllus*, *E. avenaceous* and *B. uniflora* become the dominants.

Bird's-eye *Cassia* is very palatable and although it is still of common occurrence has been depleted through grazing. *Acacia kempeana* and the small-leafed form of *Chenopodium nitrariaceum* are only slightly palatable.

In addition to the mulga association, Bon Bon soil also supports myall – bluebush or occasionally bluebush without trees (*K. sedifolia* association). Apart from tree species the three associations are floristically similar when associated with Bon Bon soil.

3. *Mulga on Wilgena soil*

When it supports *A. aneura* – *A. brachystachya* association Wilgena soil carries very scattered mulgas and herbaceous species form a sparse growth. The bluebush understorey is often not as dense as it is on Bon Bon soil. Mulga association is actually rarely found on Wilgena soil. Where the mulga and myall-bluebush association complex occurs the latter community is usually found on Wilgena soil, while further north where myall is absent, that is, in the *A. aneura* – *A. brachystachya* — *K. sedifolia* association complex country, Wilgena soil carries treeless bluebush (*K. sedifolia* association). Apart from tree species the communities are floristically similar when associated with Wilgena soil.

The mulga community on Wilgena (and Bon Bon) soil contains fewer species than it does on deep sandy (Wirraminna) soil. Apart from bluebush, fairly common shrubs are sagebush (*Trichinium obovatum*), bird's-eye Cassia and *Kochia triptera* var. *pentaptera*. Dominant herbaceous species are the bindyis (*Bassia obliquicuspis* and *B. sclerolaenoides*) and black heads (*Enneapogon cylindricus*). *E. caerulescens* and *Zygophyllum prismatothecum* are fairly common. Mistletoes (*Loranthus exocarpi* and *L. murrayi*) are common parasites on the mulgas. A complete list of species found in the association, the soils on which they grow and their palatabilities to stock are shown in Table XII.

Mulga death has been severe throughout the North-West. From numerous counts which were made it is estimated that about one-third of the mature mulgas have died on the sandy soils, while on the heavier-textured soils the proportion of dead trees is even greater. Mulga is very susceptible to death by firing. Although the fires that occur are only "grass fires" they kill up to two-thirds of the mulgas and those that survive never recover completely and die earlier than unburnt trees. On the other hand, regeneration is sometimes increased and there

may be up to half as many established mulga seedlings in the burned country as there were mature trees prior to the fire.

Changes which have occurred with grazing

The frequency of occurrence of the species on Wirraminna soil in the mulga country of the Lake Wirrida block, which has never been stocked, was compared with adjacent stocked areas. As the shrub growth on the deep sandy soils is comparatively sparse, stocking would be expected to cause rapid changes in the density and floristic composition of the shrub component of the vegetation. This is found to be the case.

Common shrubs on Wirraminna soil in ungrazed country are bluebush (*K. sedifolia*), saltbush (*A. vesicaria*), *Eremophila latrobei*, bundy bush (*Cassia eremophila* var. *platypoda*), tomato bush (*Enchylaena tomentosa*) and *Kochia georgei* (erect form). Sagebush (*Trichinium obovatum*), tar bush (*Eremophila glabra*) and *Sida virgata* are fairly common.

In grazed country bundy bush and tomato bush are still common because they are rarely grazed. The erect form of *Kochia georgei* is only slightly palatable but is thinned out to some extent under heavy grazing. *S. virgata*, which is moderately palatable, remains fairly common because of its free-seeding habit. Bluebush is moderately palatable but is very hard to kill by grazing. The very palatable *Eremophila latrobei* becomes of very rare occurrence in stocked country, while sagebush and tar bush, which are moderately palatable, become fairly rare. The ecotype of saltbush associated with sandy soils is rapidly destroyed by stock.

Australian boxthorn is protected from excessive grazing by its spines and although moderately palatable has increased. There has been a marked increase in the amount of the unpalatable firebush.

Dominant herbaceous species in ungrazed country are mulga grass (*Aristida arenaria*), *Enneapogon polyphyllus*, *E. avenaceus* and *Bassia uniflora* and on sandridges *Danthonia bipartita* and *Eragrostis eriopoda*. Although mulga grass is only moderately palatable it is an excellent drought reserve. It is not grazed to any extent when other herbaceous feed is available, but during drought times the dry grass is completely eaten. It has the additional advantage of producing new growth rapidly after a dry period following light rain and provides grazing for stock before annual herbage appears. *E. polyphyllus*, *E. avenaceus* and *B. uniflora* are much more palatable than mulga grass and are suppressed under heavy stocking. The proportion of these species to mulga grass is the best indication of the stocking to which the country is subjected.

Mulga country as a grazing unit

It has been pointed out that the mulga community is most commonly associated with sandy soils of the Wirraminna type and that shrubs are of sparse occurrence on the deeper sands. As a consequence the bush drought reserve is comparatively small. This can be readily seen by reference to the quantitative map showing the present bush density of Commonwealth Hill Station (see fig. 12) where there are large areas of mulga country not interspersed with other plant associations. When this survey was carried out most of Commonwealth Hill was virgin country.

However, the foliage and pods of the mulgas themselves are very palatable, and although stock soon trim the foliage up to the height they can reach, dry leaves are constantly shed from the trees. The dominant shrubs of the shrub-steppe communities shed their leaves during drought times and live in a state of anabiosis. The result is that the shrubs are a valuable reserve in the early stages of drought but if the dry period is prolonged they provide little more than sticks

for the stock to graze. The mulgas, however, continue to shed leaves from their canopies, so that in a prolonged drought they are of much greater value as a food reserve than shrubs.

After mulga country has been grazed for some time and an equilibrium between stocking and vegetation has been reached, the most important species in the community to the grazier are *A. arenaria, E. polyphyllus, E. avenaceus* and *Bassia uniflora*. It is not possible in practice to economically graze mulga country and maintain the balance between stock and plants to enable the ecotype of saltbush found on sandy soils or the very palatable *Eremophila latrobei* to be maintained except as very rare species.

TABLE XII

List of species found in the *Acacia aneura – A. brachystachya association*. D = dominant, VC = very common, C = common, FC = fairly common, FR = fairly rare, R = rare, VR = Very rare.

	Palatability	Natural frequency	Frequency in grazed country	Associated soil
Acacia aneura	1	D	D	All three; rare on Wilgena
Acacia brachystachya	1	D	D	All three; rare on Wilgena
Atriplex vesicaria	2	VC	VR	All three
Kochia sedifolia	3	VC	VC	Absent from deep sands
Stipa nitida	1	FR	FR	Absent from deep sands
Enneapogon polyphyllus	1	D	D	All three but most on Wirra.
Bassia uniflora	1	D	D	All three but most on Wirra.
Bassia obliquicuspis	3	FR	FC	Absent from Wirraminna
Bassia paradoxa	4	VR	R	Bon Bon and shallow Wirra.
Aristida arenaria	3	D	D	All three but rare on Wilgena
Enchylaena tomentosa	4	FC	FC	All three
Rhagodia spinescens var.	4	VR	R	All three
Kochia triptera var. erioclada	5	VR	FC	All three, particularly Wirraminna; rare on Wilgena
Lycium australe	3	FR	FC	All three
Cassia eremophila var. platypoda	4	FC	FC	Wirraminna only
Kochia georgei (erect form)	4	C	FC	Wirraminna only
Salsola kali	2	FC	FC	All three
Enneapogon avenaceus	1	C	C	All three
Erodium cygnorum	1	FR	FR	All three, particularly Bon Bon
Tetragonia expansa	1	R	R	Wirra. and Bon Bon
Tetragonia eremaea	1	R	R	Wirra. and Bon Bon
Tragus australianus	3	VR	VR	All three, partic. Wirraminna
Euphorbia drummondii	4	R	R	All three
Portulaca oleracea	2	VR	VR	Wirra. and Bon Bon
Sida virgata	3	C	FC	All three, particularly Wirra.
Eremophila latrobei	1	FC	VR	All three, particularly Wirra.
Eremophila glabra	3	FC	VR	Wirra. and Bon Bon
Eremophila scoparia	4	VR	VR	All three
Acacia burkittii	5	VR	VR	Wirra. and Bon Bon
Kochia pyramidata	5	VR	R	Wirra. and Bon Bon
Eucarya spicata	4	FC	VR	All three
Heterodendron oleifolium	1	VR	VR	Wirra. and Bon Bon
Eremophila paisleyi	4	R	R	——
Grevillea nematophylla	4	R	R	Wirra. and Bon Bon
Pentatropis kempeana	—	VR	VR	Wirra. and Bon Bon

	Palatability	Natural frequency	Frequency in grazed country	Associated soil
Eremophila duttonii	4	VR	VR	Bon Bon and Wilgena
Eremophila longifolia	3	VR	VR	Wirra. and Bon Bon
Eremophila alternifolia var. latifolia	4	FR	FR	Wirra. and Bon Bon
Sida intricata	3	VR	VR	Bon Bon and Wilgena
Abutilon leucopetalum	5	R	R	Wirra. only
Bassia divaricata	5	VR	VR	Bon Bon and Wilgena
Solanum ellipticum	5	VR	VR	All three
Goodenia spinescens	5	VR	VR	———
Acacia kempeana	4	FR	FR	All three, partic. Bon Bon
Acacia oswaldii	3	VR	VR	All three, partic. Bon Bon
Dodonaea microzyga	4	VR	VR	Bon Bon and Wilgena
Gumniopsis quadrifida	2	VR	VR	Wirra. only
Sida petrophila	4	VR	VR	All three
Cassia artemisioides	3	VR	VR	All three
Zygophyllum fruticulosum var. eremaeum	4	FR	FR	All three
Chenopodium nitrariaceum (small-leafed form)	4	VR	VR	Bon Bon and Wilgena
Bassia sclerolaenoides	3	FC	FC	Wilgena and Bon Bon
Cassia sturtii	1	FC	FR	Bon Bon and Wilgena
Templetonia egena	4	VR	VR	Wirra. and Bon Bon
Eucarya acuminata	2	VR	VR	All three
Kochia triptera var. pentaptera	5	FR	FR	Bon Bon and partic. Wilgena
Acacia tetragonophylla	4	FR	FR	All three, least on Wirra.
Kochia tomentosa	5	VR	VR	Bon Bon and Wilgena
Dodonaea attenuata	4	VR	VR	Wirra. only
Eragrostis eriopoda	4	FC	FC	Deep sands only
Danthonia bipartita	4	FC	FC	Deep sands only
Eremophila serrulata	4	VR	VR	All three
Trisetum pumillum	—	VR	VR	———
Phyllanthus lacunarius	5	VR	VR	Wirra only
Chenopodium cristatum	4	VR	VR	Wirra only
Calandrinia remota	1	VR	VR	Wirra only
Cucumis myriocarpus	4	VR	VR	Wirra. and Bon Bon
Swainsona burkittii	5	VR	VR	Wirra. only
Triraphis mollis	3	R	R	Wirra. only
Clianthus speciosus	1	VR	VR	Wirra. and Bon Bon
Zygophyllum ammophilum	4	VR	VR	All three
Euphorbia eremophila	3	R	R	Wirra only
Trichinium alopecuroideum	4	FC	FC	Wirra only
Calotis cymbacantha	3	VR	VR	Wirra. and Bon Bon
Aristida anthoxanthoides	3	VR	VR	———
Lepidium papillosum	4	VR	VR	All three
Lepidium oxytrichum	4	VR	VR	All three
Goodenia cycloptera	4	FR	FR	Wirra and Bon Bon
Citrullus vulgaris	5	VR	VR	Wirra and Bon Bon
Stenopetalum lineare	—	VR	VR	All three
Convolvulus erubescens	1	VR	VR	Wirra. only
Angianthus pusillus	4	R	R	All three
Chenopodium desertorum	3	R	R	Wirra. only

	Palatability	Natural frequency	Frequency in grazed country	Associated soil
Myriocephalus stuartii	5	VR	VR	Wirra. only
Didiscus glaucifolius	—	VR	VR	Wirra. only
Trichinium exaltatum	1	R	VR	Wirra. and Bon Bon
Enneapogon caerulescens	3	FC	FC	Bon Bon and Wilgena
Enneapogon cylindricus	3	FC	FC	Bon Bon and Wilgena
Helipterum floribundum	5	FR	FR	Wirra. and Bon Bon
Bassia eriacantha	2	FR	VR	All three
Loranthus exocarpi	1	C	C	On mulgas (parasitic)
Loranthus murrayi	1	C	C	On mulgas (parasitic)
Zygophyllum prismatothecum	5	FC	FC	All three
Dactyloctenium radulans	2	VR	VR	Wirra. and Bon Bon
Tribulus terrestris	2	VR	VR	Wirra. and Bon Bon
Acacia aneura var. latifolia	1	FR	FR	All three
Atriplex spongiosa	4	VR	VR	All three
Nicotiana sp.	5	VR	VR	All three
Craspedia pleiocephala	4	VR	VR	Wirra. and Bon Bon
Atriplex quinii	5	VR	VR	———
Trichinium obovatum	3	FR	VR	All three
Codonocarpus cotinifolius	5	VR	VR	Wirra. only

Acacia sowdenii – Kochia sedifolia association (pl. xix, fig. 3)

In this shrub-woodland community an understorey of bluebush is present beneath an open woodland of small trees of *A. sowdenii* (myall) which vary from 16-28 feet in height. Myall is the most attractive tree found in the arid country of South Australia. Prior to being grazed by stock its branches and foliage sweep to the ground (pl. xix, fig. 2) and the new foliage produced after heavy rains has a silvery-grey colour. Death of myall has not been as severe as mulga and amounts to only 15-20 per cent. of the mature trees.

A. Sowdenii has a curious distribution. Both the species itself and the myall-bluebush association occur particularly on Bon Bon but also on Wilgena soils. There are, however, large areas of these soils normally colonized by myall from which it is absent, for example in the country to the north-west of Kingoonya where the *A aneura – A. brachystachya – – K. sedifolia* association complex occurs. Here species normally associated with myall occur but myall itself is lacking. Rainfall is slightly lower than in most of the myall country, but the species does occur in more arid areas than this, for example, occasional myalls occur along wadis and creeks as far north as the south branch of the Neales River and in parts of the Denison Range.

The limited distribution of the species is probably the result of restricted colonization. The recession of plant species in South Australia during the arid Recent and their subsequent spread from centres of survival has been discussed by Crocker and Wood (1947), who suggested that myall survived in the Gawler Ranges. There were also other minor survival centres such as along creeks like the Neales "River" and in the Denison Range. The implication of the restricted spread of myall following the lifting of climatic stress during the Recent is that the period of increased rainfall was of too short duration to enable the species to migrate to all the areas it is capable of colonizing. The present rainfall is lower than during the moist period of colonization.

The species occurring in the myall-bluebush association vary with the depth of the sandy surface horizons of the soils. On the shallowest Bon Bon soils and

on Wilgena soil the herbaceous layer is dominated by black heads (*Enneapogon cylindricus*) and bindyi (*Bassia obliquicuspis*), the latter increasing with depletion through grazing of the bluebush cover. *E. caerulescens* and *B. sclerolaenoides* are prominent. On the deeper soils *E. cylindricus* and *Bassia obliquicuspis* are again dominants, but *B. sclerolaenoides* and *E. caerulescens* are of rare occurrence. *E. polyphyllus*, *E. avenaceus*, mulga grass and *B. uniflora* are very common. *B. paradoxa* may become very common when the community suffers very heavy grazing and bush death.

Bluebush is the dominant shrub but *Cratystylis conocephala* replaces it in some of the southern myall country. Australian boxthorn (*Lycium australe*) is fairly common, while *Chenopodium nitrariaceum* (small-leafed form) and firebush (*Kochia triptera* var. *erioclada*) are fairly rare. Complete floristics of the association and the palatabilities of the species are given in Table xiii.

Changes which occur with grazing

The most noticeable effects of heavy grazing are an increase in the amount of bindyi (*Bassia obliquicuspis*) and sometimes *B. paradoxa*. Black bluebush (*Kochia pyramidata*) and firebush may also spread. These species, with the exception of *B. obliquicuspis*, are of slight or no value. At the same time bluebush is depleted and *Enneapogon polyphyllus*, *E. arenaceus* and *Bassia uniflora* are suppressed. Bird's eye Cassia and bladder saltbush were more common prior to grazing. Overgrazing and death of bluebush containing an admixture of bladder saltbush may, on the sandier Bon Bon soils, result in a saltbush dominant understorey because saltbush frequently seeds heavily prior to death.

The community as a grazing unit

The foliage of *A. sowdenii* is always grazed by stock to as high as they can reach but its foliage is actually only slightly palatable, so that it is only under drought conditions that any leaves which are shed are eaten by sheep. The principal drought reserve of the myall-bluebush country is *K. sedifolia*. Apart from bluebush the most important species in the community to the grazier are black heads (*Enneapogon polyphyllus*, *E. avenaceus* and *E. cylindricus*), the bindyis (*Bassia uniflora* and *B. sclerolaenoides*) and mulga grass (*Aristida arenaria*).

TABLE XIII, showing a complete list of species found in the *A. sowdenii*—*K. sedifolia* association

Species	Palatability	Frequency of occurrence
Acacia sowdenii	4	D
Kochia sedifolia	3	D
Bassia obliquicuspis	3	VC
Lycium australe	3	FC
Chenopodium nitrariaceum	4	FR
Bassia paradoxa	4	FR
Kochia triptera var. erioclada	5	FR
Enchylaena tomentosa	4	R
Rhagodia spinescens var. deltophylla	4	R
Cassia eremophila var. platypoda	4	R
Cassia sturtii	1	R
Kochia pyramidata	5	R
Eremophila scoparia	4	R
Sida virgata	3	R
Atriplex vesicaria	2	R
Bassia divaricata	5	VR
Kochia georgei (erect form)	4	VR

Species	Palatability	Frequency of occurrence
Eucarya acuminata	2	VR
Eucarya spicata	4	VR
Grevillea nematophylla	4	VR
Kochia triptera	—	VR
Cassia eremophila	4	VR
Exocarpus aphylla	4	VR
Templetonia egena	4	VR
Eucarya persicarius	—	VR
Dodonaea microzyga	4	VR
Myoporum platycarpum	2	VR
Eremophila duttonii	4	VR
Eremophila serrulata	4	VR
Heterodendron oleifolium	1	VR
Acacia tetragonophylla	4	VR
Eremophila rotundifolia	5	VR
Eremophila alternifolia	4	VR
Eremophila alternifolia var. latifolia	4	VR
Acacia kempeana	4	VR
Acacia oswaldii	3	VR
Trichinium obovatum	3	VR
Acacia burkittii	5	VR
Eremophila latrobei	1	VR
Eremophila paisleyi	4	VR
Sida intricata	3	VR
Pittosporum phillyreoides	2	VR
Eremophila longifolia	3	VR
Cassia artemisioides	3	VR
Zygophyllum fruticolosum	4	VR
Kochia tomentosa	5	VR
Kochia triptera var. pentaptera	5	VR
Enneapogon cylindricus	3	D
Aristida arenaria	3	C
Bassia uniflora	1	FC
Enneapogon polyphyllus	1	FC
Enneapogon avenaceus	1	FC
Zygophyllum prismatothecum	5	FC
Salsola kali	2	FC
Bassia sclerolaenoides	3	R
Tetragonia expansa	1	R
Tetragonia eremaea	1	R
Erodium cygnorum	1	R
Enneapogon caerulescens	3	R
Stipa nitida	1	FR
Euphorbia drummondii	4	VR
Chenopodium desertorum	3	VR
Eragrostis setifolia	2	VR
Goodenia cycloptera	4	VR
Tribulus terrestris	2	VR
Sida petrophila	4	VR
Tragus australianus	3	VR
Triraphis mollis	3	VR
Babbagia dipterocarpa	5	VR

Zygophyllum ammophilum	4	VR
Craspedia pleiocephala	4	VR
Atriplex spongiosa	4	VR
Clianthus speciosus	1	VR
Zygophyllum compressum	4	VR
Loranthus exocarpi	1	VR
Loranthus murrayi	1	VR

Kochia sedifolia association (Plate XIX, Figure 4)

Treeless shrub steppe areas dominated by bluebush are found on Bon Bon and Wilgena soils beyond the range of myall. The floristics of the community vary according to the soil.

1. *K. sedifolia* association on Wilgena soil

K. triptera var. *pentaptera* is a common associated shrub and sagebush (*Trichinium obovatum*) is fairly common. Dead-finish (*Acacia tetragonophylla*) is fairly rare. The dominant herbaceous species are bindyis (*Bassia sclerolaenoides* and *B. obliquicuspis*) and *Enneapogon cylindricus*, while *E. caerulescens*, buck bush (*Salsola kali*) and *Bassia uniflora* are fairly rare.

2. *K. sedifolia* association on Bon Bon soil

Soapbush (*Zygophyllum fruticulosum*), sagebush (*Trichinium obovatum*) and bird's eye Cassia (*Cassia sturtii*) are fairly common associated shrubs. Broombush (*Eremophila scoparia*) is fairly rare. The dominant herbaceous species are bindyi (*Bassia obliquicuspis*) and *Enneapogon cylindricus*, while *E. caerulescens*, *E. avenaceus*, *E. polyphyllus*, *Bassia sclerolaenoides* and buck bush (*Salsola kali*) are fairly rare. Complete floristics of the association are given in Table XIV.

Changes which occur with grazing

Heavy grazing of the community on both Wilgena and Bon Bon soils causes depletion of bluebush, bladder saltbush and *Cassia sturtii* and increase in bindyi (*Bassia obliquicuspis*). Sagebush (*Trichinium obovatum*) is depleted where the community is on Wilgena soil. The grasses *Enneapogon polyphyllus* and *E. avenaceus* and the bindyi *Bassia uniflora* are also suppressed under heavy grazing.

TABLE XIV

showing complete floristics of the *K. sedifolia* association

Species	Frequency on Bon Bon soil	Frequency on Wilgena soil	Palatability
Kochia sedifolia	D	D	3
Bassia obliquicuspis	VC	C	3
Zygophyllum fruticulosum	FC	VR	4
Trichinium obovatum	FC	FC	3
Cassia sturtii	FC	VR	1
Eremophila scoparia	FR	VR	4
Lycium australe	R	VR	3
Rhagodia spinescens var. deltophylla	VR	VR	4
Enchylaena tomentosa	VR	VR	4
Cassia artemisioides	VR	VR	3
Sida virgata	VR	VR	3
Chenopodium nitrariaceum	VR	R	4
Sida corrugata	VR	VR	4
Sida intricata	VR	VR	3

Species	Frequency on Bon Bon soil	Frequency on Wilgena soil	Palatability
Casuarina cristata	VR	VR	4
Eremophila rotundifolia	VR	R	5
Kochia tomentosa	VR	R	4
Kochia pyramidata	VR	—	5
Eremophila duttonii	VR	VR	4
Acacia oswaldii	VR	VR	3
Acacia tetragonophylla	VR	FR	4
Dodonaea microzyga	VR	VR	4
Goodenia spinescens	VR	—	5
Eremophila alternifolia	VR	VR	4
Eremophila alternifolia var. latifolia	VR	—	4
Solanum ellipticum	VR	VR	5
Bassia paradoxa	VR	VR	4
Acacia kempeana	VR	VR	4
Eremophila latrobei	VR	VR	1
Bassia divaricata	VR	VR	5
Kochia triptera var. pentaptera	VR	C	5
Enneapogon cylindricus	D	D	3
Enneapogon caerulescens	FR	FR	3
Bassia sclerolaenoides	FR	VC	3
Enneapogon avenaceus	FR	VR	1
Enneapogon polyphyllus	FR	VR	1
Salsola kali	FR	FR	2
Bassia uniflora	R	FR	1
Aristida arenaria	R	VR	3
Atriplex vesicaria	VR	VR	2
Kochia triptera var. erioclada	VR	VR	5
Zygophyllum prismatothecum	VR	R	5
Vittadinia triloba	VR	—	4
Stipa nitida	R	R	1
Sida petrophila	VR	VR	4
Portulaca oleracea	VR	—	2
Abutilon leucopetalum	VR	—	5
Blennodia trisecta	VR	—	—
Stenopetalum lineare	VR	VR	—
Calotis cymbacantha	VR	—	3
Danthonia semiannularis	VR	—	1
Lepidium oxytrichum	VR	VR	4
Lepidium papillosum	VR	VR	4
Helipterum floribundum	VR	—	5
Craspedia pleiocephala	VR	—	4
Zygophyllum iodiocarpum	VR	—	4
Erodium cygnorum	VR	VR	1
Goodenia cycloptera	VR	—	4
Bassia eriacantha	—	VR	2
Santalum lanceolatum	VR	VR	1
Euphorbia drummondii	VR	VR	4

Acacia linophylla – A. ramulosa association (Plate XX, Figure 1)

These two species, which grow to a height of 9-14 feet, are the dominants on the sandhills in the southern portion of the North-West. Black oak (*Casuarina*

cristata) is of common occurrence with the acacias on the sandhills south of the east-west railway line. North of the railway line black oak is of rare occurrence on the dunes but pine (*Callitris glauca*) partly or completely replaces the acacias on some of the sandhills (pl. xx, fig. 2). Shrub species, with the exception of *Cassia eremophila* var. *platypoda* which is very common on Roxby Downs Station, are of rare occurrence in the community. *Aristida browniana* is the dominant herbaceous species. Commonly associated with it are *Plagiosetum refractum, Enneapogon polyphyllus, E. avenaceus, Salsola kali* and *Atriplex vellutinellum. Triraphis mollis* is fairly common. The following species are common after winter rains: parakeelya (*Calandrinia remota*), *Blennodia canescens,* Stuart's daisy (*Myriocephalus stuartii*), *Angianthus pusillus, Calotis cymbacantha* and *Helichrysum semifertile.*

Practically all of the dunes in the southern sandhill country carry this stable climax community, but some of the dunes superimposed upon the tableland and immediately surrounding it are unstable. Primary colonizers of these unstable dunes are *Salsola kali, Atriplex velutinellum, Crotalaria dissitiflora* and *Myriocephalus stuartii.* The first shrubs to appear are sandhill wattle (*Acacia ligulata*) and hop bush (*Dodonaea attenuata*).

Complete floristics of the association are given in Table XV.

The sandhills as a grazing unit.

The dominant acacias have unpalatable foliage and shrubs are practically absent, so the sandhill country is of little value in drought times. Further, the dominant herbaceous species (*Aristida browniana*) is a coarse unpalatable grass. The community is most valuable to the grazier following winter rains when a dense growth of ephemeral species is produced. However, if the preceding summer rains have been heavy the growth of grass, particularly *A. browniana,* is frequently so dense as to allow little space for annual species.

TABLE XV

showing complete floristics of the *Acacia linophylla – A. ramulosa* association.

Species	Palatability	Frequency of occurrence
Acacia linophylla	4	D
Acacia ramulosa	4	D
Casuarina cristata	4	C
Callitris glauca	5	C
Cassia eremophila var. platypoda	4	FC
Acacia ligulata	5	VR
Heterodendron oleifolium	1	R
Dodonaea attenuata	4	VR
Abutilon leucopetalum	5	R
Eucarya spicata	4	VR
Duboisia hopwoodii	5	VR
Eremophila paisleyi	4	R
Pittosporum phillyreoides	2	VR
Kochia triptera	—	R
Enchylaena tomentosa	4	R
Hakea leucoptera	5	VR
Sida intricata	3	VR
Grevillea nematophylla	4	R
Myoporum montanum	—	VR
Phyllanthus fuernrohrii	5	R

Species	Palatability	Frequency of occurrence
Cassia sturtii - - - -	1	VR
Phyllanthus lacunarius - - -	5	FR
Bassia uniflora - - - -	1	R
Eucalyptus pyriformis - - -	5	VR
Bossiaea walkeri - - - -	5	VR
Aristida browniana - - -	4	D
Plagiosetum refractum - - -	3	C
Enneapogon polyphyllus - -	1	C
Enneapogon avenaceus - - -	1	C
Salsola kali - - - - -	2	C
Atriplex velutinellum - - -	5	C
Triraphis mollis - - - -	3	FC
Stipa nitida - - - - -	1	R
Citrullus vulgaris - - - -	5	R
Cucumis myriocarpus - - -	4	R
Didiscus glaucifolius - - -	—	R
Aristida arenaria - - - -	3	FR
Euphorbia drummondii - -	4	R
Euphorbia eremophila - - -	3	VR
Lepidium oxytrichum - - -	4	VR
Lepidium papillosum - - -	4	VR
Zygophyllum iodocarpum - -	4	R
Crotalaria dissitiflora - - -	4	VR
Convolvulus erubescens - -	1	R
Clianthus speciosus - - -	1	VR
Calandrinia remota - - -	1	FC
Blennodia canescens - - -	2	FC
Myriocephalus stuartii - - -	5	FC
Angianthus pusillus - - -	4	FC
Calotis cymbacantha - - -	3	FC
Helichrysum semifertile - -	—	FC
Tetragonia expansa - - -	1	R
Tetragonia eremaea - - -	1	R
Trisetum pumillum - - -	—	VR
Nicotiana sp. - - - -	5	VR
Goodenia cycloptera - - -	4	R
Zygophyllum ammophilum - -	4	R
Stenopetalum lineare - - -	—	VR
Atriplex spongiosa - - -	4	R

Zygochloa paradoxa association (Plate XX, Figure 3)

Sandhills in the Lake Eyre region are completely covered with scattered plants of sandhill canegrass (*Zygochloa paradoxa* formerly *Spinifex paradoxus*), a sclerophyllous grass which is more akin to the hard-leaved shrubs than the usual soft-leaved herbaceous grasses. It has a palatability rating of 4. In the adjacent Simpson Desert the crests of the dunes are bare (Crocker, 1946). Herbaceous growth is always much sparser than on the *Acacia* spp. sandhills further south.

Shrub species which commonly occur with the canegrass are sandhill wattle (*Acacia ligulata*) and hop bush (*Dodonaea attenuata*), while *Trichinium obovatum* and *Phyllanthus fuernrohrii* are fairly common. Common herbaceous species are caltrop (*Tribulus terrestris*), *Aristida browniana* and *Crotalaria dissitiflora,*

while the following are fairly common: mulga grass, bur grass (*Tragus australianus*), buck bush, *Plagiosetum refractum*, *Myriocephalus stuartii* and *Euphorbia drummondii*. Complete floristics are given in Table XVI.

The sandy flats between the dunes carry a modified mulga community. Spinifex (*Triodia basedowii*), which is the dominant species between the dunes in the Simpson Desert (Crocker, 1946), is absent. The mulgas are very scattered. Hop bush, sandhill wattle, *Eremophila duttonii* and needlebush (*Hakea leucoptera*) are the most common shrubs. Canegrass sometimes extends onto the flats where the sands are very deep. Mulga grass is the dominant herbaceous species on the sandy flats. Typical associated species are *Enneapogon polyphyllus*, *E. avenaceus*, *Citrullus vulgaris*, *Cucumis myriocarpus*, *Abutilon leucopetalum*, *Euphorbia drummondii*, *Crotalaria dissitiflora* and button grass (*Dactyloctenium radulans*).

TABLE XVI

showing the species present in the *Zygochloa paradoxa* association

Species	Frequency of occurrence
Zygochloa paradoxa	D
Acacia ligulata	C
Dodonaea attenuata	C
Trichinium obovatum	FC
Phyllanthus fuernrohrii	FC
Eremophila sp.	FR
Acacia aneura	VR
Acacia brachystachya	VR
Sida virgata	VR
Sida petrophila	VR
Gumniopsis quadrifida	VR
Tribulus terrestris	C
Aristida browniana	C
Crotalaria dissitiflora	C
Aristida arenaria	FC
Tragus australianus	FC
Salsola kali	FC
Plagiosetum refractum	FC
Myriocarpus stuartii	FC
Euphorbia drummondii	FC
Phyllanthus lacunarius	FR
Triraphis mollis	FR
Portulaca oleracea	FR
Enneapogon polyphyllus	FR
Enneapogon avenaceus	FR
Cucumis myriocarpus	FR
Atriplex spongiosa	R
Abutilon leucopetalum	R
Trianthema crystallina var. clavata	VR
Trichodesma zeylanicum var. sericeum	VR
Nicotiana sp.	VR
Eragrostis eriopoda	VR
Zygophyllum howittii	VR
Aristida anthoxanthoides	VR
Citrullus vulgaris	VR
Tetragonia spp.	VR

Eremophila freelingii – Acacia aneura – A. brachystachya association.

The Denison Range south of Oodnadatta supports a hill-woodland community dominated by *E. freelingii* and mulgas (*Acacia aneura* and *A. brachystachya*).

Acacia aneura – A. brachystachya – A. tetragonophylla association
(Plate XX, Figure 4)

These species are the dominants of the association found in watercourses and "swamps" on transported soils in the Mount Eba depression. Shrubs are generally not conspicuous, the community being an arid woodland. Prickly acacia (*Acacia victoriae*) and *Sida virgata* are fairly rare, while *Trichinium obovatum, Eremophila rotundifolia, Bassia divaricata* and cotton bush (*Kochia aphylla*) are rare.

The dominant herbaceous species are mulga grass (*Aristida arenaria*) and bindyi (*Bassia paradoxa*), while button grass (*Dactyloctenium radulans*) and *B. uniflora* are fairly rare. *Salsola kali, Eragrostis falcata, Enneapogon polyphyllus* and *E. avenaceus* are rare. Complete floristics are given in Table XVII.

TABLE XVII

showing the species present in the *A. aneura – A. brachystachya – A. tetragonophylla* association.

Species	Palatability	Frequency of occurrence
Acacia aneura	1	D
Acacia brachystachya	1	D
Acacia tetragonophylla	4	D
Bassia paradoxa	4	C
Bassia uniflora	1	FR
Acacia victoriae	3	FR
Sida virgata	3	FR
Trichinium obovatum	3	R
Eremophila rotundifolia	5	R
Bassia divaricata	5	R
Kochia aphylla	4	R
Cassia sturtii	1	VR
Kochia pyramidata	5	VR
Eremophila paisleyi	4	VR
Zygophyllum fruticulosum	4	VR
Santalum lanceolatum	1	VR
Eremophila longifolia	3	VR
Pittosporum phillyreoides	2	VR
Exocarpus aphylla	4	VR
Eremophila duttonii	4	VR
Rhagodia spinescens	4	VR
Sida intricata	3	VR
Bassia eriacantha	2	VR
Eremophila serrulata	4	VR
Cassia artemisioides	3	VR
Cassia desolata	4	VR
Cassia phyllodinea	4	VR
Heterodendron oleifolium	1	VR
Acacia oswaldii	3	VR
Eremophila scoparia	4	VR
Eremophila maculata	4	VR

Species	Palatability	Frequency of occurrence
Bassia patenticuspis	2	VR
Enchylaena tomentosa	4	VR
Solanum ellipticum	5	VR
Bassia sclerolaenoides	3	VR
Atriplex vesicaria	2	VR
Kochia lobiflora	—	VR
Aristida arenaria	3	D
Dactyloctenium radulans	2	FR
Salsola kali	2	R
Eragrostis falcata	3	R
Enneapogon avenaceus	1	R
Enneapogon polyphyllus	1	R
Sida petrophila	4	VR
Stenopetalum lineare	—	VR
Zygophyllum ammophilum	4	VR
Abutilon leucopetalum	5	VR
Zygophyllum compressum	4	VR
Stipa nitida	1	VR
Lepidium papillosum	4	VR
Blennodia trisecta	—	VR
Teucrium racemosum	3	VR
Helichrysum cassinianum	—	VR
Erodium cygnorum	1	VR
Minuria leptophylla	4	VR
Eragrostis setifolia	2	VR
Marsilia drummondii	4	VR
Rhagodia nutans	3	VR
Goodenia cycloptera	4	VR
Phyllanthus lacunarius	5	VR
Eragrostis dielsii	1	VR
Atriplex spongiosa	4	VR
Citrullus vulgaris	5	VR
Aristida anthoxanthoides	3	VR
Portulaca oleracea	2	VR
Cucumis myriocarpus	4	VR
Euphorbia drummondii	4	VR
Tetragonia expansa	1	VR
Tetragonia eremaea	1	VR
Convolvulus erubescens	1	VR
Tribulus terrestris	2	VR
Enneapogon cylindricus	3	VR
Clianthus speciosus	1	VR
Eulalia fulva	1	VR
Ixiolaena leptolepis	4	VR
Helipterum floribundum	5	VR

Kochia planifolia–*Bassia* spp. association (Plate XXI, Figure 1).

This shrub steppe community is also found on transported soils in the Mount Eba depression but on slightly more elevated sites than the *Acacia aneura*–*A. brachystachya*–*A. tetragonophylla* association. It is associated with low terraces between watercourses. *Kochia planifolia* is always of sparse occurrence on Mount Eba soil. Because of this low natural density of low bluebush grazing

causes rapid destruction of the bush cover. Further, fairly heavy bush death occurs on this soil under drought conditions even when stocking is light.

The association is generally devoid of trees but scattered mulga (*Acacia aneura* and *A. brachystachya*) and dead finish (*A. tetragonophylla*) may be present. In addition to low bluebush, *Bassia paradoxa* and *B. divaricata* are very common species. Dominant herbaceous species are *Bassia eriacantha, B. uniflora* and mulga grass. Complete floristics are given in Table XVIII.

Small crabholes are a common feature of the country and here, in addition to species mentioned above, the following occur: cotton bush (*Kochia aphylla*) is a dominant shrub, while *Ixiolaena leptolepis* is very common and *Atriplex vesicaria* is common. *Eremophila maculata* is fairly common. *Eragrostis falcata* is a common grass in the crabholes.

Changes which occur with grazing:

The *A. aneura – A. brachystachya – A. tetragonophylla* and *Kochia planifolia – Bassia* spp. associations form an association complex and are best discussed together. Heavy grazing results in increase in the amount of *Bassia paradoxa* and *B. divaricata,* while *B. uniflora* and *B. eriacantha* are suppressed. Low bluebush and bladder saltbush are depleted under grazing. The free-seeding rapid growing prickly acacia (*A. victoriae*) has spread in the watercourses during the last few years.

The association complex as a growing unit:

Due to the common occurrence of clay very near the soil surface the herbaceous cover is fairly patchy, even in good seasons. During drought years much of the country is completely devoid of plant growth. However, the community occurs in low lying sites and is particularly valuable to the grazier in good seasons. The principal drought reserve is now mulga, low bluebush having practically all been destroyed through grazing. Many of the most common shrubs are of little or no value. Most important species in the pasture are *Bassia uniflora, Acacia victoriae, Sida virgata,* mulga grass, button grass and *Bassia eriacantha.*

TABLE XVIII

showing the species found in the *K. planifolia – Bassia* spp. association.

Species	Palatability	Frequency of occurrence
Kochia planifolia	2	D
Bassia eriacantha	2	D
Bassia paradoxa	4	D
Bassia divaricata	5	D
Bassia uniflora	1	D
Acacia aneura	1	R
Acacia brachystachya	1	R
Acacia tetragonophylla	4	R
Atriplex quinii	5	FC
Trichinium obovatum	3	FR
Bassia brachyptera	4	R
Eremophila rotundifolia	5	R
Eremophila duttonii	4	R
Atriplex vesicaria	2	R
Cassia sturtii	1	VR
Kochia pyramidata	5	VR
Sida virgata	3	VR
Pittosporum phillyreoides	2	VR

Species	Palatability	Frequency of occurrence
Cassia eremophila	4	VR
Kochia triptera var. pentaptera	5	VR
Bassia obliquicuspis	3	VR
Sida intricata	3	VR
Cassia artemisioides	3	VR
Acacia oswaldii	3	VR
Enchylaena tomentosa	4	VR
Bassia tricuspis	5	VR
Exocarpus aphylla	4	VR
Eremophila alternifolia	4	VR
Solanum ellipticum	5	VR
Eremophila paisleyi	4	VR
Ixiolaena leptolepis	4	VR
Bassia lanicuspis	3	VR
Cassia desolata	4	VR
Cassia phyllodinea	4	VR
Eremophila latrobei	1	VR
Dodonaea microzyga	4	VR
Aristida arenaria	3	D
Salsola kali	2	FR
Enneapogon polyphyllus	1	R
Enneapogon avenaceus	1	R
Angianthus pusillus	4	VR
Stenopetalum lineare	—	VR
Portulaca oleracea	2	VR
Nicotiana sp.	5	VR
Zygophyllum ammophilum	4	VR
Lepidium oxytrichum	4	VR
Stipa nitida	1	VR
Babbagia dipterocarpa	5	VR
Lepidium papillosum	4	VR
Blennodia trisecta	5	VR
Helichrysum cassinianum	—	VR
Erodium cygnorum	1	VR
Goodenia cycloptera	4	VR
Panicum decompositum	3	VR
Dactyloctenium radulans	2	VR
Euphorbia drummondii	4	VR
Tribulus terrestris	2	VR
Enneapogon cylindricus	3	VR
Clianthus speciosus	1	VR
Eulalia fulva	1	VR
Helipterum floribundum	5	VR
Euphorbia eremophila	3	VR
Astrebla pectinata	3	VR
Tragus australianus	3	VR
Kochia aphylla	4	D
Eremophila maculata	4	FR
Bassia echinopsila	—	VR
Bassia ventricosa	3	VR
Eragrostis falcata	3	C
Rhagodia nutans	3	VR
Chloris acicularis	3	VR

Kochia planifolia association.

This shrub steppe community is associated with Twins soil. Low bluebush is the dominant species but bladder saltbush is of common occurrence. These species may be uniformly distributed (Plate XXI, Figure 2) but over wide areas growth is restricted to slight depressions where the soil is an inch or two deeper and where the moisture status is somewhat higher (Plate XXI, Figure 3).

Sagebush (*Trichinium obovatum*) and *Aizoon zygophylloides* are shrubs of fairly common occurrence, while broombush (*Eremophila scoparia*) and native pittosporum (*Pittosporum phillyreoides*) are fairly rare. The principal herbaceous plants in the community are buck bush (*Salsola kali*), button grass (*Dactyloctenium radulans*) and *Aristida anthoxanthoides*. Fairly common are *Enneapogon cylindricus* and *Trianthema crystallina* var. *clavata*. Complete floristics are given in Table XIX.

The community as a grazing unit.

The *K. planifolia* association has a lower carrying capacity than any other community in the North-West. The density of low bluebush and bladder saltbush is generally fairly low even where the community is well preserved. Further, the poor water-retaining capacity of the soil has resulted in widespread bush death under drought conditions, with the result that living bush is restricted to watercourses and slopes of undulations over much of the country. Due to its greater regeneration capacity there is a tendency for bladder saltbush to become the dominant species in place of low bluebush.

During most seasons the growth of herbage and grass is extremely sparse, large areas where shale is exposed being devoid of growth.

TABLE XIX

showing the species present in the *K. planifolia* association.

Species	Palatability	Frequency of occurrence
Kochia planifolia	2	D
Atriplex vesicaria	2	VC
Aizoon zygophylloides	5	FC
Trichinium obovatum	3	FC
Pittosporum phillyreoides	2	FR
Eremophila scoparia	4	FR
Acacia tetragonophylla	4	R
Kochia tomentosa	4	VR
Rhagodia spinescens var. deltophylla	4	VR
Solanum ellipticum	5	VR
Sida corrugata	4	VR
Eremophila rotundifolia	5	VR
Eremophila oppositifolia	4	VR
Atriplex quinii	5	VR
Bassia patenticuspis	2	VR
Acacia oswaldii	3	VR
Bassia divaricata	5	VR
Kochia aphylla	4	VR
Kochia pyramidata	5	VR
Bassia eriacantha	2	VR
Bassia lanicuspis	3	VR
Bassia biflora	—	VR
Heterodendron oleifolium	1	VR
Santalum lanceolatum	1	VR

Species	Palatability	Frequency of occurrence
Enchylaena tomentosa - - -	4	VR
Bassia obliquicuspis - - -	3	VR
Bassia uniflora - - - -	1	VR
Bassia paradoxa - - - -	4	VR
Kochia triptera var. pentaptera -	5	VR
Arthrocnemum sp. - - - -	5	VR
Kochia eriantha - - - -	1	VR
Chenopodium nitrariaceum (small leafed form) - - - -	4	VR
Sida virgata - - - - -	3	VR
Bassia sclerolaenoides - - -	3	VR
Lycium australe - - - -	3	VR
Eremophila alternifolia - - -	4	VR
Cassia sturtii - - - - -	1	VR
Zygophyllum apiculatum - -	5	VR
Eremophila longifolia - - -	3	VR
Zygophyllum fruticulosum - -	4	VR
Salsola kali - - - - -	2	C
Dactyloctenium radulans - -	2	C
Aristida anthoxanthoides - -	3	C
Enneapogon cylindricus - - -	3	FC
Trianthema crystallina var. clavata	—	FC
Chloris acicularis - - - -	3	FR
Aristida arenaria - - - -	3	R
Portulaca oleracea - - - -	2	R
Enneapogon avenaceus - - -	1	R
Enneapogon polyphyllus - - -	1	R
Tribulus terrestris - - - -	2	VR
Lotus australis var. parviflorus -	4	VR
Zygophyllum prismatothecum -	5	VR
Tetragonia eremaea - - -	1	VR
Stipa nitida - - - - -	1	VR
Euphorbia drummondii - -	4	VR
Convolvulus erubescens - - -	1	VR
Euphorbia eremophila - - -	3	VR
Tragus australianus - - -	3	VR
Sporobolus actinocladus - - -	1	VR
Panicum decompositum - - -	3	VR
Babbagia dipterocarpa - - -	5	VR
Zygophyllum ammophilum - -	4	VR
Erodium cygnorum - - -	1	VR
Bassia brachyptera - - - -	4	VR
Chloris truncata - - - -	3	VR
Sida petrophila - - - -	4	VR
Trichinium erubescens - - -	—	VR

Atriplex vesicaria – Kochia planifolia association (Plate XXI, Figure 4).

This shrub steppe community is associated with Coondambo soil. The dominant species are bladder saltbush and low bluebush. Scattered trees of mulga (*Acacia aneura*), umbrella mulga (*A. brachystachya*) or myall (*A. sowdenii*) are occasionally present. Coondambo soil is characterised by light-textured A horizons overlying clay at shallow depth. However, watercourses which drain

Coondambo soil areas frequently have deeper sandy A horizons overlying the clay. On these soils little *K. planifolia* is associated with bladder saltbush.

Star bush (*Gumniopsis quadrifida*) is a common associated shrub, while *Bassia ventricosa, B. decurrens,* broombush (*Eremophila scoparia*) and *Sida virgata* are fairly rare. The dominant herbaceous species are *Enneapogon polyphyllus, E. avenaceus, Bassia uniflora* and mulga grass (*Aristida arenaria*), while button grass (*Dactyloctenium radulans*) and neverfail (*Eragrostis dielsii*) are fairly common. Complete floristics are given in Table XX.

The community as a grazing unit:

The *A. vesicaria–K. planifolia* association has a greater stock carrying capacity than any other plant community found in the North-West. Bladder saltbush and low bluebush are both palatable species and constitute an excellent drought reserve. In this association they form a very dense bush stand in ungrazed areas and competition for moisture is so severe that even in favourable seasons little herbage and grass appears among the bushes. Some thinning of bush is necessary to enable herbage and grass to appear in the community and thus increase its grazing value.

Gumniopsis quadrifida is the most important associated shrub to the grazier. All of the common herbaceous plants are very valuable species.

Changes which occur with grazing:

Bladder saltbush and low bluebush are both grazed to about the same extent but saltbush is not as resistant to grazing as bluebush, so that heavy grazing results in alteration of the proportion of saltbush to bluebush in favour of bluebush. However, saltbush is a more prolific seeder and regenerates much more readily than bluebush, so that spelling or reduced stocking of country which has been heavily grazed restores the original proportion of saltbush and bluebush.

Under heavy grazing the herbaceous species *Enneapogon polyphyllus, E. avenaceus, Bassia uniflora* and *Eragrostis dielsii* are suppressed. All these species are quite palatable and together with button grass and mulga grass constitute the principal pasturage. *Bassia paradoxa,* which is of little value, colonizes sand mounds where scalding has occurred. On the exposed clay of the scalded areas *Bassia divaricata, B. ventricosa* and *B. obliquicuspis* are common.

TABLE XX

showing the species present in the *A. vesicaria–K. planifolia* association.

Species	Palatability	Frequency of occurrence
Atriplex vesicaria - - - -	2	D
Kochia planifolia - - - -	2	D
Gumniopsis quadrifida - - -	2	C
Bassia uniflora - - - -	1	C
Bassia ventricosa - - - -	3	FR
Sida virgata - - - - -	3	FR
Eremophila scoparia - - -	4	FR
Bassia decurrens - - - -	3	FR
Bassia lanicuspis - - - -	3	VR
Kochia tomentosa var. appressa -	4	VR
Kochia pyramidata - - - -	5	VR
Bassia paradoxa - - - -	4	VR
Kochia aphylla - - - -	4	VR
Cassia sturtii - - - - -	1	VR
Eremophila duttonii - - -	4	VR
Bassia obliquicuspis - - -	3	VR
Bassia divaricata - - - -	5	VR

Species	Palatability	Frequency of occurrence
Kochia triptera var. erioclada	5	VR
Kochia ciliata	—	VR
Heterodendron oleifolium	1	VR
Acacia burkittii	5	VR
Goodenia spinescens	5	VR
Solanum ellipticum	5	VR
Dodonaea microzyga	4	VR
Eremophila alternifolia	4	VR
Acacia tetragonophylla	4	VR
Pittosporum phillyreoides	2	VR
Kochia triptera var. pentaptera	5	VR
Eremophila longifolia	3	VR
Sida intricata	3	VR
Sida corrugata	4	VR
Trichinium obovatum	3	VR
Cassia phyllodinea	4	VR
Euphorbia eremophila	3	VR
Enneapogon polyphyllus	1	D
Enneapogon avenaceus	1	D
Aristida arenaria	3	D
Dactyloctenium radulans	2	FC
Eragrostis dielsii	1	FC
Tragus australianus	3	FR
Salsola kali	2	FR
Portulaca oleracea	2	FR
Atriplex spongiosa	4	FR
Erodium cygnorum	1	FR
Euphorbia drummondii	4	R
Triraphis mollis	3	VR
Zygophyllum crenatum	4	VR
Convolvulus erubescens	1	VR
Zygophyllum ammophilum	4	VR
Zygophyllum compressum	4	VR
Tribulus terrestris	2	VR
Lepidium papillosum	4	VR
Enneapogon cylindricus	3	VR
Tetragonia eremea	1	VR
Enneapogon caerulescens	3	VR
Trianthema crystallina var. clavata	—	VR
Chenopodium cristatum	4	VR
Stipa nitida	1	VR
Stenopetalum lineare	—	VR
Lotus australis var. parviflorus	4	VR
Craspedia pleiocephala	4	VR
Helipterum floribundum	5	VR
Clianthus speciosus	1	VR
Atriplex halimoides var. conduplicatum	4	VR
Citrullus vulgaris	5	VR
Bassia brachyptera	4	VR
Babbagia dipterocarpa	5	VR
Angianthus pusillus	4	VR
Bassia sclerolaenoides	3	VR
Brachycome iberidifolia var. glandulifera	4	VR

Atriplex vesicaria – Bassia spp. association (Plate XXII, Figure 1).

This shrub steppe community, whose occurrence at Yudnapinna station has previously been described by Crocker and Skewes (1941), is associated with Coober Pedy soil. Growth is practically restricted to the crabholes where they are present, while elsewhere a sparse growth occurs over the country as a whole.

A. vesicaria and *Bassia* spp. are the dominant shrubs. Of the *Bassias*, *B. ventricosa* is common while *B. paradoxa* and *B. tricuspis* are fairly rare. *B. divaricata* and *B. lanicuspis* are rare. In addition to these cotton bush (*Kochia aphylla*) and low bluebush (*K. planifolia*) are of fairly rare occurrence. Dominant herbaceous species are *Eragrostis falcata*, button grass (*Dactyloctenium radulans*), *Enneapogon polyphyllus*, and *E. avenaceus*. Mitchell grass (*Astrebla pectinata*) is common, while the following are fairly common: *Aristida anthoxanthoides*, pop saltbush (*Atriplex spongiosa*), sugar grass (*Eulalia fulva*) and *Bassia brachyptera*.

Changes which occur with grazing:

Even in ungrazed areas the density of bladder saltbush is low on Coober Pedy soil, so that under drought conditions the bush that is present is subjected to heavy grazing. Little saltbush therefore remains in most of the stocked paddocks. If, however, the country is spelled while sufficient seed-producing plants remain, regeneration during favourable years is fairly rapid as the ecotype of saltbush associated with these clay soils is a prolific seeder and a vigorous plant.

Bindyis, particularly *Bassia paradoxa* and *B. divaricata*, but also *B. ventricosa*, increase under heavy grazing. Annual species like pop saltbush (*Atriplex spongiosa*) also spread. At the same time the black head grasses (*Enneapogon polyphyllus* and *E. avenaceus*) become thinned out.

TABLE XXI

showing the species present in the *A. vesicaria – Bassia* spp. association.

Species	Palatability	Frequency of occurrence
Atriplex vesicaria - - - -	2	D
Bassia ventricosa - - - -	3	C
Bassia paradoxa - - - -	4	FR
Bassia tricuspis - - - -	5	FR
Bassia divaricata - - - -	5	R
Bassia lanicuspis - - - -	3	R
Kochia aphylla - - - -	4	FR
Kochia planifolia - - - -	2	FR
Atriplex quinii - - - -	5	VR
Sida intricata - - - - -	3	VR
Ixiolaena leptolepis - - -	4	VR
Sida virgata - - - - -	3	VR
Minuria denticulata - - - -	4	VR
Trichinium obovatum - - -	3	VR
Kochia pyramidata - - -	5	VR
Bassia eriacantha - - - -	2	VR
Bassia tricornis - - - -	—	VR
Eragrostis falcata - - - -	3	D
Dactyloctenium radulans - -	2	D
Enneapogon polyphyllus - -	1	D
Enneapogon avenaceus - - -	1	D
Astrebla pectinata - - - -	3	C

Species	Palatability	Frequency of occurrence
Aristida anthoxanthoides	3	C
Atriplex spongiosa	4	C
Eulalia fulva	1	C
Bassia brachyptera	4	C
Bassia uniflora	1	FR
Salsola kali	2	FR
Portulaca oleracea	2	FR
Trianthema crystallina var. clavata	—	FR
Panicum decompositum	3	FR
Aristida arenaria	3	R
Minuria leptophylla	4	R
Sida corrugata var. trichopoda	4	VR
Lotus australis var. parviflorus	4	VR
Convolvulus erubescens	1	VR
Euphorbia drummondii	4	VR
Tragus australianus	3	VR
Babbagia dipterocarpa	5	VR
Sporobolus actinocladus	1	VR
Enneapogon cylindricus	3	VR
Erodium cygnorum	1	VR
Iseilema vaginiflorum	2	VR
Goodenia cycloptera	4	VR
Frankenia serpyllifolia	5	VR
Rhagodia nutans	3	VR
Zygophyllum ammophilum	4	VR
Tetragonia eremaea	1	VR
Atriplex halimoides var. conduplicatum	4	VR
Cucumis myriocarpus	4	VR
Citrullus vulgaris	5	VR
Epaltes cunninghamii	—	VR
Marsilia drummondii	4	VR
Chloris acicularis	3	VR

Atriplex vesicaria – Ixiolaena leptolepis association (Plate XXII, Figure 2).

This community is found on Arcoona soil in the tableland country west of Lake Torrens. Murray (1931) has described the vegetation of a portion of the tablelands and called the community the "saltbush association". It is advisable, however, to retain the name *Atriplex vesicaria* association for the saltbush dominant community found in north-eastern South Australia, where saltbush occurs almost to the exclusion of other tree or shrub species (Wood 1937). Murray (1931) includes bluebush (*Kochia sedifolia*) and black bluebush (*K. pyramidata*) in the tableland vegetation. These species are constituents of other plant associations and are never present in the *A. vesicaria – I. leptolepus* association of the tableland proper.

The habitat is a gently rolling plateau characterised by the complete absence of trees and tall shrubs except along creeks. Most of the vegetation does not exceed a height of 18". There are really two habitats, the crabholes where most of the vegetation is found and the more arid and saline shelves which are practically devoid of growth.

The dominant species are *A. vesicaria* and *I. leptolepis*. *Minuria leptophylla* is usually associated. Common shrubs and under-shrubs are samphires (*Arthroc-*

nemum leiostachyum and *Pachycornia tenuis*) and *Psoralea* sp., while *Minuria denticulata, Sida corrugata* var. *trichopoda, Abutilon halophilum, Bassia ventricosa, Atriplex halimoides* and *A. halimoides* var. *conduplicatum* are fairly common. The most prominent herbaceous species are the grasses *Eragrostis setifolia* and *E. falcata*. Very common are mitchell grass (*Astrebla pectinata*), *Panicum decompositum*, ray grass (*Sporobolus actinocladus*) and *Lotus australis* var. *parviflorus*, while *Paspalidium* sp., *Swainsona stipularis, Bassia brachyptera, Erodium cygnorum, Eulalia fulva, Atriplex spongiosa, Helipterum strictum* and *Goodenia cycloptera* are fairly common.

The gibber-covered shelves between the crabholes are either devoid of plant growth or carry a very scattered growth of *Bassia ventricosa* and *B. brachyptera*. Less common on the shelves are *Arthrocnemon leiostachyum, Pachycornia tenuis, B. divaricata* and *Kochia tomentosa* var. *appressa*, while *B. sclerolaenoides* and *K. eriantha* are very rarely present.

In addition to the species listed above for the tableland, there are other plants which are only associated with creeks. The following small trees and shrubs are typical of tableland creeks: *Acacia brachystachya, A. aneura, A. tetragonophylla, A. rigens, A. oswaldii, Eremophila alternifolia, E. serrulata, E. duttonii, E. oppositifolia, E. glabra, Pittosporum phillyreoides, Santalum lanceolatum, Hakea leucoptera, Dodonaea lobulata, Prostanthera striatiflora, Cassia sturtii, Heterodendron oleifolium* and *Casuarina cristata*. Commonly occurring smaller shrubs and undershrubs are *Enchylaena tomentosa, Rhagodia spinescens, Kochia aphylla, K. spongiocarpa, Atriplex vesicaria, Sida virgata, S. petrophila* and more rarely *K. planifolia* and *Bassia limbata*.

Herbaceous plants typical of creek beds are *Aristida nitidula, Isotoma petraea, Morgania glabra, Trichinium erubescens, Cucumis myriocarpus, Citrullus vulgaris, Eragrostis australasica* and rarely *Psoralea patens, Helipterum floribundum, Bassia uniflora, Aristida anthoxanthoides, Orobanche australiana, Thysanotus baueri* and *Abutilon leucopetalum*.

Following the exceptionally heavy rains of 1946 and 1947 Coolymilka Lake, which is a depression in tableland country, contained about 20 feet of water at its deepest part. By October 1947 the water level had fallen about five feet. Near the waterline *Erythraea australis, Epaltes cunninghamii, Calotis hispidula, Atriplex spongiosa, Trigonella suavissima* and *Heliotropium curassavicum* were recorded. The lake is fringed by ti-trees (*Melaleuca pubescens* and *M. pauperifolia*).

In addition to the normal crabholes of the tableland some large depressions occur which are best regarded as swamps. Canegrass (*Eragrostis australasica*) is usually the dominant species, but occasionally *Chenopodium nitrariaceum* and *Muehlenbeckia cunninghamii* occur as dominants. Associated species are *Calotis hispidula, Trigonella suavissima, Teucrium racemosum, Erythraea australis, Ranunculus parviflorus* and nardoo (*Marsilia drummondii*). Around the fringes of these swamps species typical of the *A. vesicaria – I. leptolepis* association are found.

The community as a grazing unit:

The tableland country has a fairly low stock-carrying capacity because much of the area is occupied by gibber-covered shelves largely devoid of plant growth. However, the presence of crabholes into which water drains from the surrounding shelf areas ensures some grazing for stock after most rains. An outstanding feature of the wool from sheep grazing on tableland country is its cleanliness. This is due to the mantle of gibbers on the soil surface.

With the exception of *A. vesicaria* most of the common and fairly common shrub spec'es are only slightly palatable. Bladder saltbush is therefore the prin-

cipal drought reserve. Grasses (*Eragrostis setifolia, E. falcata, Sporobolus actinocladus, Eulalia fulva, Astrebla pectinata* and *Panicum decompositum*) are the most valuable members of the community to the grazier.

Changes which occur with grazing:

With intensive grazing of the crabhole vegetation the bindyis *Bassia divaricata, B. ventricosa, B. paradoxa* and *B. tricuspis* spread. Apart from *B. ventricosa* these species are of little or no value. Competition with other plants in ungrazed and lightly grazed crabholes restricts the bindyis principally to the crabhole fringes and the arid shelves. Heavy grazing also causes an increase in annual or unpalatable species like *Atriplex spongiosa, Trianthema crystallina* and the poisonous *Lotus australis* var. *parviflorus*. *A. vesicaria* tends to be replaced by the less palatable and less drought resistant *A. halimoides* and *A. halimoides* var. *conduplicatum*.

TABLE XXII

showing the species occurring in the *A. vesicaria–I. leptolepis* association.

Species	Palatability	Natural frequency	Frequency in grazed country
Atriplex vesicaria	2	D	D
Ixiolaena leptolepis	4	D	D
Minuria leptophylla	4	C	VC
Pachycornia tenuis	4	C	C
Arthrocnemum leiostachyum	4	C	C
Psoralea sp.	3	C	C
Minuria denticulata	4	FC	FC
Sida corrugata var. trichopoda	4	C	C
Abutilon halophilum	4	FC	FC
Atriplex halimoides	4	R	FC
Atriplex halimoides var. conduplicatum	4	R	FC
Bassia divaricata	5	R	FR
Bassia ventricosa	3	FR	FC
Bassia tricuspis	5	VR	FR
Bassia paradoxa	4	R	FR
Acacia rigens	4	R	R
Kochia aphylla	4	R	R
Bassia brachyptera	4	FC	FC
Kochia georgei (low form)	2	VR	VR
Kochia planifolia	2	VR	VR
Kochia spongiocarpa	—	VR	VR
Kochia ciliata	—	VR	VR
Kochia tomentosa var. appressa	4	VR	VR
Bassia biflora	—	VR	VR
Bassia lanicuspis	3	VR	VR
Sida intricata	3	VR	R
Sida corrugata	4	VR	VR
Atriplex fissivalve	—	VR	VR
Sarcostemma australe	5	VR	VR
Kochia eriantha	1	VR	VR
Eragrostis falcata	3	VC	VC
Eragrostis setifolia	2	VC	VC
Astrebla pectinata	3	VC	VC
Panicum decompositum	3	VC	VC
Sporobolus actinocladus	1	VC	VC
Lotus australis var. parviflorus	4	C	VC

Species	Palatability	Natural frequency	Frequency in grazed country
Paspalidium sp.	2	FC	FC
Swainsona stipularis	—	FC	FC
Erodium cygnorum	1	FC	FC
Eulalia fulva	1	FC	FC
Helipterum strictum	4	FC	FC
Goodenia pinnatisecta	4	FC	FC
Trianthema crystallina	—	R	FR
Dactyloctenium radulans	2	FR	FR
Atriplex spongiosa	4	FR	FC
Eragrostis australasica	4	FR	FR
Trigonella suavissima	1	FR	FR
Eriochloa longiflora	1	FR	FR
Euphorbia eremophila (leafless form)	3	FR	FR
Calotis hispidula	5	FR	FR
Plantago varia	—	FR	FR
Stipa nitida	1	R	R
Babbagia dipterocarpa	5	R	R
Enneapogon avenaceus	1	R	R
Daucus glochidiatus	—	R	R
Aristida anthoxanthoides	3	R	R
Mesembryanthemum aequilaterale	4	R	R
Frankenia serpyllifolia	5	R	R
Teucrium racemosum	3	R	R
Ranunculus parviflorus	—	R	R
Marsilia drummondii	4	R	R
Marsilia hirsuta	4	R	R
Chloris truncata	3	R	R
Helipterum floribundum	5	R	R
Epaltes cunninghamii	4	R	R
Eragrostis dielsii	1	R	R
Lepidium oxytrichum	4	R	R
Zygophyllum fruticulosum var. eremaeum	4	R	R
Zygophylum ammophilum	4	R	R
Zygophyllum compressum	4	R	R
Tetragonia eremaea	1	R	R
Erythraea australis	—	R	R
Bassia uniflora	1	R	R
Tragus australianus	3	R	R
Portulaca oleracea	2	R	R
Bassia sclerolaenoides	3	VR	VR
Trichinium erubescens	—	VR	VR
Anacampseros australiana	1	VR	VR
Iseilema vaginiflorum	2	VR	VR

Atriplex rhagodioides association (Plate XXII, Figure 3).

On the Arcoona soils of the tableland country west of Lake Eyre a shrub steppe association dominated by silver saltbush (*Atriplex rhagodioides*) is found. This community is floristically similar to the *A. vesicaria*–*I. leptolepis* association which occurs on similar soils further south, but a few of the southern species are absent. Most of the growth is restricted to the crabholes.

Chenopods are prominent among the shrubs. Common species associated with *A. rhagodioides* are flat-topped saltbush (*A. halimoides* and *A. halimoides*

var. *conduplicatum*) and *Bassia ventricosa,* while *Abutilon halophilum, Sida corrugata* var. *trichopoda,* cotton bush (*Kochia aphylla*) and *Ixiolaena leptolepis* are fairly common. The most prominent herbaceous species are grasses of which *Eragrostis falcata, E. setifolia,* flinders grass (*Iseilema vaginiflorum*), mitchell grass (*Astrebla pectinata*), *Aristida anthoxanthoides* and ray grass (*Sporobolus actinocladus*) are most common. Fairly common are *Panicum decompositum, Bassia brachyptera,* pop saltbush (*Atriplex spongiosa*), *Threlkeldia proceriflora,* sugar grass (*Eulalia fulva*) and *Swainsona stipularis.*

There are several interesting differences between this association found in the northern tableland country and that occurring west of Lake Torrens. *Atriplex rhagodioides* replaces *A. vesicaria* as the dominant species and *Ixiolaena leptolepis* is not as common as it is further south. Samphires (*Arthrocnemum leiostachyum* and *Pachycornia tenuis*) are of less frequent occurrence, but *Kochia aphylla* is much more conspicuous. The common grasses are the same in both associations except that flinders grass (*Iseilema vaginiflorum*) is much more common in the Lake Eyre region than further south. Canegrass (*Eragrostis australasica*), which is present in the crabholes of the southern tableland country and which gives a characteristic facies to the vegetation, is not present in the crabholes further north.

The community as a grazing unit:

The *A. rhagodiodes* association has a very low stock-carrying capacity. Apart from the absence of growth on the shelves between the crabholes, areas of highly gypseous soils totally devoid of plant growth are common and the rainfall of the habitat is the lowest recorded in Australia.

A. rhagodioides is unpalatable, so that *Bassia* species do not invade heavily grazed crabholes as they do in the *A. vesicaria – I. leptolepis* association.

TABLE XXIII

showing the species present in *Atriplex rhagodioides* association.

Species	Frequency of occurrence
Atriplex rhagodioides	D
Atriplex halimoides	C
Atriplex halimoides var. conduplicatum	C
Bassia ventricosa	C
Abutilon haliphilum	FC
Sida corrugata var. trichopoda	FC
Kochia aphylla	FC
Ixiolaena leptolepis	FC
Arthrocnemum leiostachyum	FR
Pachycornia tenuis	FR
Bassia divaricata	FR
Atriplex vesicaria	R
Bassia paradoxa	R
Minuria leptophylla	R
Kochia eriantha	VR
Eragrostis falcata	VC
Eragrostis setifolia	VC
Iseilema vaginiflorum	VC
Astrebla pectinata	VC
Aristida anthoxanthoides	VC
Sporobolus actinocladus	VC
Panicum decompositum	FC
Bassia brachyptera	FC
Atriplex spongiosa	FC

Species	Frequency of occurrence
Threlkeldia proceriflora - - - - -	FC
Eulalia fulva - - - - - -	FC
Swainsona stipularis - - - - -	FC
Enneapogon polyphyllus - - - -	R
Enneapogon avenaceus - - - - -	R
Euphorbia drummondii - - - -	R
Marsilia drummondii - - - - -	R
Salsola kali - - - - - - -	R
Dactyloctenium radulans - - - -	R
Portulaca oleracea - - - - -	VR
Trianthema crystallina var. clavata - -	VR
Chloris acicularis - - - - -	VR
Babbagia dipterocarpa - - - - -	VR
Tragus australianus - - - - -	VR
Goodenia cycloptera - - - - -	VR
Calotis hispidula - - - - - -	VR
Erodium cygnorum - - - - -	VR
Trigonella suavissima - - - - -	VR
Paspalidium sp. - - - - - -	VR
Daucus glochidiatus - - - - -	VR
Aristida arenaria - - - - - -	VR
Lotus australis var. parviflorus - - -	VR
Atriplex quinii - - - - - -	VR
Frankenia scrpyllifolia - - - - -	VR
Bassia lanicuspis - - - - - -	VR
Bassia uniflora - - - - - -	VR
Sarcostemma australe - - - - -	VR
Lepidium oxytrichum - - - - -	VR

Kochia planifolia – Atriplex vesicaria – K. sedifolia association.

K. planifolia is a species which grows upon soils with a clay subsoil at shallow depth, while *K. sedifolia* is associated with soils containing heavy lime. Both heavy textured and calcareous soils are suitable for the growth of *A. vesicaria.* As a consequence these three species are the codominants of a shrub steppe community on the heavy textured calcareous Miller's Creek soil.

Very few shrubs are associated with the dominants, the following being the only ones recorded: *Trichinium obovatum, Kochia tomentosa, Sida corrugata* and very rare *Acacia oswaldii, Heterodendron oleifolium* and *Sida virgata.*

The principal herbaceous species are bindyis (*Bassia obliquicuspis* and *B. sclerolaenoides*), *Enneapogon cylindricus, Zygophyllum prismatothecum* and *Salsola kali.* Of rare occurrence are *Z. glaucescens, E. caerulescens, Goodenia cycloptera, Erodium cygnorum, Tribulus terrestris* and *Convolvulus erubescens,* while the following are very rare: *Euphorbia drummondii, Bassia uniflora, Citrullus vulgaris, Cucumis myriocarpus, Enneapogon avenaceus* and *E. polyphyllus.*

The community as a grazing unit:

Severe bush death has occurred through grazing and droughts on the Miller's Creek soil even among the very hardy *K. sedifolia,* with the result that there is now little drought reserve. Further, even in good seasons the growth of herbage and grass is very sparse, so the community has a very low stock-carrying capacity.

The plant communities associated with swamps, watercourses and creeks.

Mulga Swamps

Small depressions liable to inundation following heavy rains are a feature of the mulga and myall woodlands. A well-defined drainage pattern is lacking, the "swamps" being merely the result of very local drainage. They are characterized typically by a dense thicket of mulgas (*A. aneura* and *A. aneura* var. *latifolia*) and umbrella mulga (*A. brachystachya*). *Chenopodium nitrariaceum* commonly forms an understorey with nardoo (*Marsilia drummondii*) as a ground layer. Lignum (*Muehlenbeckia cunninghamii*) is found occasionally. *Epaltes cunninghamii* and *Eragrostis falcata* are not as prominent as nardoo in the ground layer but are usually present. *Chenopodium nitrariaceum* replaces mulgas in the centre of swamps which have a larger water intake.

Many species are found around the fringes of the swamps where the mulgas are less dense. Sometimes broombush (*Melaleuca uncinata*) or ti-tree (*M. pubescens*) form a ring around the mulga thicket. The following shrubs are of general occurrence around the fringes: Australian boxthorn (*Lycium australe*), dead finish (*Acacia tetragonophylla*), *Bassia paradoxa*, tomato bush (*Enchylaena tomentosa*) and *Rhagodia spinescens*. More rarely *Ixiolaena leptolepis*, *Kochia triptera* var. *erioclada*, *K. triptera* var. *pentaptera*, *Sida intricata* and *B. obliquicuspis* are found.

Very rarely broombush (*Eremophila scoparia*), *Santalum lanceolatum*, *B. divaricata*, *B. tricuspis*, bullock bush (*Heterodendron oleifolium*), *Cassia artemisioides*, *Trichinium obovatum*, *Acacia ligulata*, *A. oswaldii*, *Kochia planifolia*, *K. pyramidata*, *Atriplex vesicaria*, *Grevillea nematophylla*, *Eucarya acuminata*, *Zygophyllum glaucescens*, *Z. fruticolosum*, *Acacia burkittii*, *Eremophila serrulata*, *E. alternifolia* and *Sida virgata* are found.

The three herbaceous species characteristically found in the centre of swamps are *Marsilia drummondii, Epaltes cunninghamii and Eragrostis falcata*. Composites are very common in the area surrounding the centre of the swamps where the following plants were recorded: *Euphorbia drummondii*, *Eragrostis dielsii*, *Calotis hispidula*, *Tetragonia expansa*, *T. eremaea*, *Atriplex spongiosa*, *Brachycome iberidifolia* var. *glandulifera*, *Dactyloctenium radulans*, *Calotis cymbacantha*, *Chenopodium cristatum*, *Goodenia subintegra*, *Craspedia pleiocephala*, *Helichrysum cassinianum*, *Stipa nitida*, *Aristida arenaria*, *Lepidium papillosum*, *L. oxytrichum*, *Gnephosis cyathopappa*, *Teucrium racemosum*, *Rutidosis helichrysoides*, *Brachycome ciliaris* var. *lanuginosa*, *Gnaphalium luteo-album*, *Helipterum semifertile* and *H. strictum*.

Of rarer occurrence are *Stenopetalum lineare*, *Convolvulus erubescens*, *Triraphis mollis*, *Lotus australis* var. *parviflorus*, *Salsola kali*, *Erodium cygnorum*, *Euphorbia eremophila*, *Enneapogon avenaceus*, *E. polyphyllus*, *Cucumis myriocarpus*, *Erythraea australis*, *Rhagodia nutans*, *Aristida anthoxanthoides*, *Emex australis*, *Bassia uniflora*, *B. sclerolaenoides*, *Blennodia canescens*, *Danthonia semiannularis*, *Vittadinia triloba*, *Clianthus speciosus*, *Portulaca oleracea*, *Stipa eremophila* and *Chenopodium murale*.

Melaleuca spp. swamps.

Some of the larger swamps carry broombush (*Melaleuca uncinata*) and ti-tree (*M. pubescens*) as the dominant species. In other cases *M. uncinata* is found throughout the centre of the swamp surrounded by a ring of *M. pubescens* or the reverse may occur. These swamps generally have a larger water intake than the mulga swamps, being fed by well-defined watercourses. Ti-tree indicates more saline soil conditions due to intake of more saline waters than broombush. As a result the two species are a useful surface indication of the quality of the ground water, better stock water being obtained by boring in broombush rather

than ti-tree swamps. On Ingomar station the red sandridges around the claypans carry *M. uncinata*. Bamboo Swamp on Billa Kalina station, which is a large claypan carrying some canegrass, is fringed by *M. uncinata*.

Atriplex nummularia (old man saltbush) swamps.

The only *A. nummularia* swamp in the sheep country of the North-West is on Miller's Creek station in a small depression in tableland country (fig. 2). *A. nummularia* is found on saline soils of floodplains and along some of the creek channels in the vicinity of Coward Springs. The principal associated species are nitre bush (*Nitraria schoberi*) and samphire (*Arthrocnemum* sp.).

Canegrass (Eragrostis australasica) swamps.

The largest swamps are characterised by the absence of mulgas and *Melaleuca* spp. except in the fringes. There are three zones in the vegetation. In the centre, that is in the area most frequently flooded, canegrass is the dominant species. Around the canegrass is a zone dominated by *Chenopodium nitrariaceum*, while mulgas and a number of shrub and small tree species occur around the margins.

The only shrubs associated with canegrass in the centre of the swamps are lignum (*Muehlenbeckia cunninghamii*) and *Chenopodium nitrariaceum*. The following herbaceous species form a sparse ground cover: *Teucrium racemosum*, *Aristida anthoxanthoides*, neverfail (*Eragrostis dielsii*), nardoo (*Marsilia drummondii*), button grass (*Dactyloctenium radulans*), pop saltbush (*Atriplex spongiosa*), bur grass (*Tragus australianus*), munyeroo (*Portulaca oleracea*) and *Trianthema crystallina* var. *clavata*. Native clover (*Trigonella suavissima*) grows in a few of the swamps.

Apart from the dominant species the most characteristic plants of the *Chenopodium nitrariaceum* zone are *Eragrostis falcata* and *Teucrium racemosum*. Associated herbaceous species are the same as those found in the fringes.

Around the margins of the swamps scattered *Chenopodium nitrariaceum* occurs with a variety of small trees and shrubs. The most characteristic of these are mulgas (*Acacia aneura*, *A. aneura* var. *latifolia* and *A. brachystachya*), dead finish (*A. tetragonophylla*), prickly acacia (*A. victoriae*), button bush (*Kochia aphylla*), and tar bush (*Eremophila glabra*). Occasional native plum trees (*Santalum lanceolatum*), broombush (*Melaleuca uncinata*), *Muehlenbeckia cunninghamii*, *Grevillea nematophylla* and *Sida intricata* are also present. Herbaceous species are *Eragrostis falcata*, *Teucrium racemosum*, *Aristida arenaria*, *A. anthoxanthoides*, *Salsola kali*, *Bassia obliquicuspis*, *B. lanicuspis*, *Dactyloctenium radulans*, *Euphorbia drummondii*, *Trianthema crystallina* var. *clavata*, *Portulaca oleracea*, *Atriplex elachophyllum* and *Morgania glabra*. *Frankenia serpyllifolia* is found around the margins of the more saline swamps.

Smaller watercourses and creeks in shrub steppe areas.

The watercourses and smaller creeks which run through Twins and Coober Pedy soil areas are lined by mulga (*Acacia aneura*) and umbrella mulga (*A. brachystachya*) and a number of shrub species, some of which are absent from the surrounding country. Commonly occurring shrub and small tree species are dead finish (*Acacia tetragonophylla*), native pittosporum (*Pittosporum phillyreoides*) and saltbush (*Atriplex vesicaria*). Associated with these are *Eremophila scoparia*, *E. duttonii*, *E. longifolia*, *Atriplex quinii*, *Kochia planifolia*, *K. pyramidata*, *Enchylaena tomentosa*, *Rhagodia spinescens* var. *deltophylla*, *Santalum lanceolatum*, *Lycium australe*, *Trichinium obovatum*, *Heterodendron oleifolium*, *Sida intricata*, *Solanum ellipticum*, *Acacia victoriae*, *A. oswaldii*, *Cassia artemisioides*, *Abutilon leucopetalum*, *Bassia paradoxa* and *B. divaricata*. Some of the creeks carry *Eucalyptus oleosa* (Plate XXII, Figure 4).

Herbaceous species are *Enneapogon polyphyllus, E. avenaceus, Dactyloctenium radulans, Eulalia fulva, Chloris acicularis, C. truncata, Bassia patenticuspis, B. lanicuspis, B. obliquicuspis, B. uniflora, Zygophyllum ammophilum, Paspalidium gracile, Eragrostis falcata, E. dielsii, Convolvulus erubescens, Aristida arenaria, A. anthoxanthoides, Euphorbia drummondii, Tetragonia eremaea, T. expansa, Tragus australianus, Trianthema crystallina* var. *clavata, Cucumis myriocarpus, Citrullus vulgaris, Goodenia cycloptera, Rhagodia nutans, Themeda avenacea* and *Chenopodium cristatum.*

Larger watercourses and creeks in shrub steppe areas.

The larger creeks consist of one or two main channels with occasional long narrow waterholes, but where they flood out they assume more the characteristics of watercourses and consist of numerous interlacing channels with a few waterholes (Plate XXIII, Figure 1). The main channels and waterholes are fringed by coolibah trees (*Eucalyptus coolabah*)—Plate XXIII, Figure 2—and sometimes mulga (*Acacia aneura* and *A. brachystachya*). In and between the channels the characteristic shrub species are canegrass (*Eragrostis australasica*), cotton bush (*Kochia aphylla*), lignum (*Muehlenbeckia cunninghamii*) and *Bassia bicornis.* The following are comparatively rare: *Ixiolaena leptolepis, Santalum lanceolatum, Hakea leucoptera, Eremophila glabra, Acacia victoriae,* dead finish (*A. tetragonophylla*) and *Minuria leptophylla.* Rarely creeks are found carrying Broughton willows (*Acacia salicina*) and *A. stenophylla.*

Associated common herbaceous species are *Eragrostis falcata,* Murray lily (*Crinum pedunculatum*), pop saltbush (*Atriplex spongiosa*) and *Portulaca oleracea.* Of rarer occurrence are *Dactyloctenium radulans, Chloris acicularis,* nardoo (*Marsilia drummondii*), *Epaltes cunninghamii, Teucrium racemosum, Frankenia serpyllifolia, Bassia divaricata, B. ventricosa, Enneapogon polyphyllus, Aristida anthoxanthoides, Cucumis myriocarpus, Citrullus vulgaris, Chenopodium cristatum, Morgania glabra, Eragrostis dielsii, Lavatera plebeja, Astrebla pectinata, Plantago varia, Erodium cygnorum, Calotis hispidula, Iseilema vaginiflorum, Euphorbia drummondii, Paspalidium gracile* and *Goodenia cycloptera.*

Creeks of the northern tableland country.

The tableland country west of Lake Eyre is drained by a large number of creeks which have their origin in tableland "ranges", that is, in high tableland areas or among residual hills. In addition some of the creeks, like the Douglas and Umbum, rise in the Denison Range south of Oodnadatta, that is among hills consisting of Precambrian rocks.

Numbers of small creeks originating near the western margin of the tableland link up as they progress in an easterly direction and form very large creeks the most important of which are The Neales, Peake, Margaret and Warriner creeks and the Macumba creek which more or less separates the tableland country from the sandy Simpson Desert. The creek beds are sandy or stony in their upper reaches and clayey in the flood plains around Lake Eyre. Unlike the creeks which reach Lake Eyre on its eastern side, those draining the tableland on the western side of the Lake frequently discharge water into it after heavy rains.

Red gums (*Eucalyptus camaldulensis*) fringe the main creek beds in their upper reaches where the soils are sandy and stony. Here the soil moisture is less saline and the moisture-status is considerably higher than further down the creeks because water flows in their upper reaches after rains which are not sufficient to cause a general flow. Apart from an occurrence on Elizabeth and Pernatty creeks red gums are restricted to creeks in the far north, the most southerly gums being on Anna and Evelyn creeks. Red gums are restricted to the

main creek beds, the subsidiary creeks carrying mulgas (*Acacia aneura* and *A. brachystachya*), *Eremophila freelingii* and *A. gilesiana* in the western portion and *E. freelingii* and gidgea (*Acacia cambagei*) in the eastern portion of the North-West.

Red gums are confined to the upper reaches of the creeks. Further down they carry coolibah (*Eucalyptus coolabah*) with mulga in the western portion and gidgea in the eastern portion of the North-West. The most southerly gidgea creek is the so-called Mulga Creek south of Coward Springs. This is an isolated occurrence, the nearest gidgea being on Douglas Creek about 60 miles north of Mulga Creek. Along the north-south railway line the most southerly gidgea creek is north of Edward's Creek railway siding. In the western portion of the North-West gidgea is not found far south of The Neales, while its most westerly occurrence is at Gypsum Bore about 50 miles west of Oodnadatta. Throughout the area where gidgea and coolibah occur on the creeks the main channels carry more coolibah than gidgea, while subsidiary creeks carry gidgea alone (pl. xxiii, fig. 3). South of the gidgea country the creeks are fringed by coolibah either alone or with mulga. The most southerly coolibah is on Miller's and Birthday Creeks.

Associated shrubs and small trees are *Acacia stenophylla*, lignum (*Muehlenbeckia cunninghamii*) prickly acacia (*A. victoriae*), *A. salicina*, *A. tetragonophylla*, *Rhagodia spinescens* var. *deltophylla*, *Grevillea nematophylla*, *Dodonaea attenuata*, *Cassia sturtii*, *Solanum ellipticum* and *Ixiolaena leptolepis*. Nitre bush (*Nitraria schoberi*) is common on the floodplains.

Quantitative Estimations and Mapping of Bush Density

The dominant shrub species, that is the bluebushes (*Kochia sedifolia* and *K. planifolia*) and saltbush (*Atriplex vesicaria*), are very important constituents of arid pastures. Although sheep cannot exist for long periods on any of these species, when they are partly defoliated under drought conditions and when no herbage or grass is available, they are extremely valuable as a drought reserve and play a very important role in minimising soil erosion. The presence of these quite palatable and highly drought-resistant perennials means that fluctuations in sheep numbers due to seasonal conditions are much smaller than in areas where shrubs are absent and grazing is dependent on herbage and grass.

When this survey was commenced it was recognised that some rapid method of estimating the density of shrub dominants and of mapping pastoral areas on this basis would have to be developed. The delineation of the boundaries of the different vegetation associations alone does not give an adequate picture of the grazing potential. It is also necessary to indicate the state of preservation of the country. To enable the large areas involved to be traversed a method depending upon visual estimations of density was used but at the same time the method had to give a sufficiently detailed picture to enable station managers to see what bush losses had occurred through grazing on the properties under their control, and to enable significant changes in bush density that might occur in the future to be measured.

Certain fairly well-defined stages of degeneration of shrub dominant vegetation can be recognised and the following categories were adopted:

- Stage 1 Unstocked country or country which has suffered only slight bush thinning.
- Stage 2 Noticeable bush thinning but the country still very well preserved. Slight increase in the amount of *Bassia* spp.
- Stage 3 Marked bush thinning. Pronounced growth of *Bassia* spp.

Stage 4 Little bush remaining through the *Bassia* spp.
Stage 5 Trace of bush remaining; mainly *Bassia* spp.
Stage 6 All bush gone. Ground layer dominated by *Bassia* spp.

The next step was to define these stages according to the number of bushes per unit area that each represented. Counts were made of bush numbers in each stage of degeneration by running one-tenth mile traverses with a car. By marking the point of commencement, driving one-tenth mile by the speedometer and walking back the plants are easily counted because the tyre marks remain plainly visible. This gives a strip five feet wide or a basal area 2/33 of an acre. All subsequent figures refer to the number of bushes in this unit of area. All bushes whose butts are on or within the wheelmarks are counted. When making the counts it is necessary to choose stands consisting of mature bushes, as seedlings often grow more densely than plants in a mature bush stand.

The following are the bush numbers on 2/33 acre areas for country in which *Kochia sedifolia* is the dominant species:

Stage 1 more than 46 bushes (Plate XXIII, Figure 4),
Stage 2 35 – 45 (Plate XXIV, Figure 1),
Stage 3 15 – 34 Plate XIX, Figure 3),
Stage 4 5 – 14 (Plate XXIV, Figure 2),
Stage 5 1 – 4 (Plate XXIV, Figure 3),
Stage 6 0;

while for *Atriplex vesicaria* and *K. planifolia* dominant areas the figures are as follows:

Stage 1 more than 160 bushes (Plate XXI, Figure 4),
Stage 2 135 –159 (Plate XXIV, Figure 4),
Stage 3 55 –134 (Plate XXV, Figure 1),
Stage 4 15 – 54 (Plate XXV, Figure 2),
Stage 5 1 – 14 (Plate XXV, Figure 3),
Stage 6 0.

However, bush density varies not only with the grazing treatment the country receives but also with the type of soil. Thus the lower stages do not always indicate degeneration from Stage 1 density. For example, when *K. sedifolia* grows on Wilgena soil the density of the bluebush is never sufficient to give a count of more than 29 bushes on 2/33 acre, so that even prior to stocking this type of country is never better than Stage 3. Stage 1 country is therefore the standard to which lower densities due to either grazing or soil type are referred.

To determine the amount of bush lost through grazing it is therefore necessary to record not only the present bush density but also to estimate the probable density of bush prior to grazing. A good correlation exists between the type of soil and the density of the bush that it supports. Thus, as pointed out, Wilgena soil supports Stage 3 *K. sedifolia* in unstocked and well-preserved areas throughout the North-West, so that even when all the bush has been removed by grazing it is reasonable to assume that originally the areas of this soil had a bush density equal to Stage 3. In addition to this correlation between soil and bush density, other evidence of the original density of the bush cover usually exists. It can often be determined from observations of adjacent paddocks, remains of dead bushes or portions of paddocks furthest away from stock watering points.

The maps showing bush density (fig. 12 and 13) are prepared from records compiled by making car traverses across the country on as detailed a grid as can be obtained. It is often possible to achieve sufficient coverage by driving the station tracks which link up the watering points and thus traverse all the paddocks. Where sufficient coverage cannot be obtained in this way it is necessary

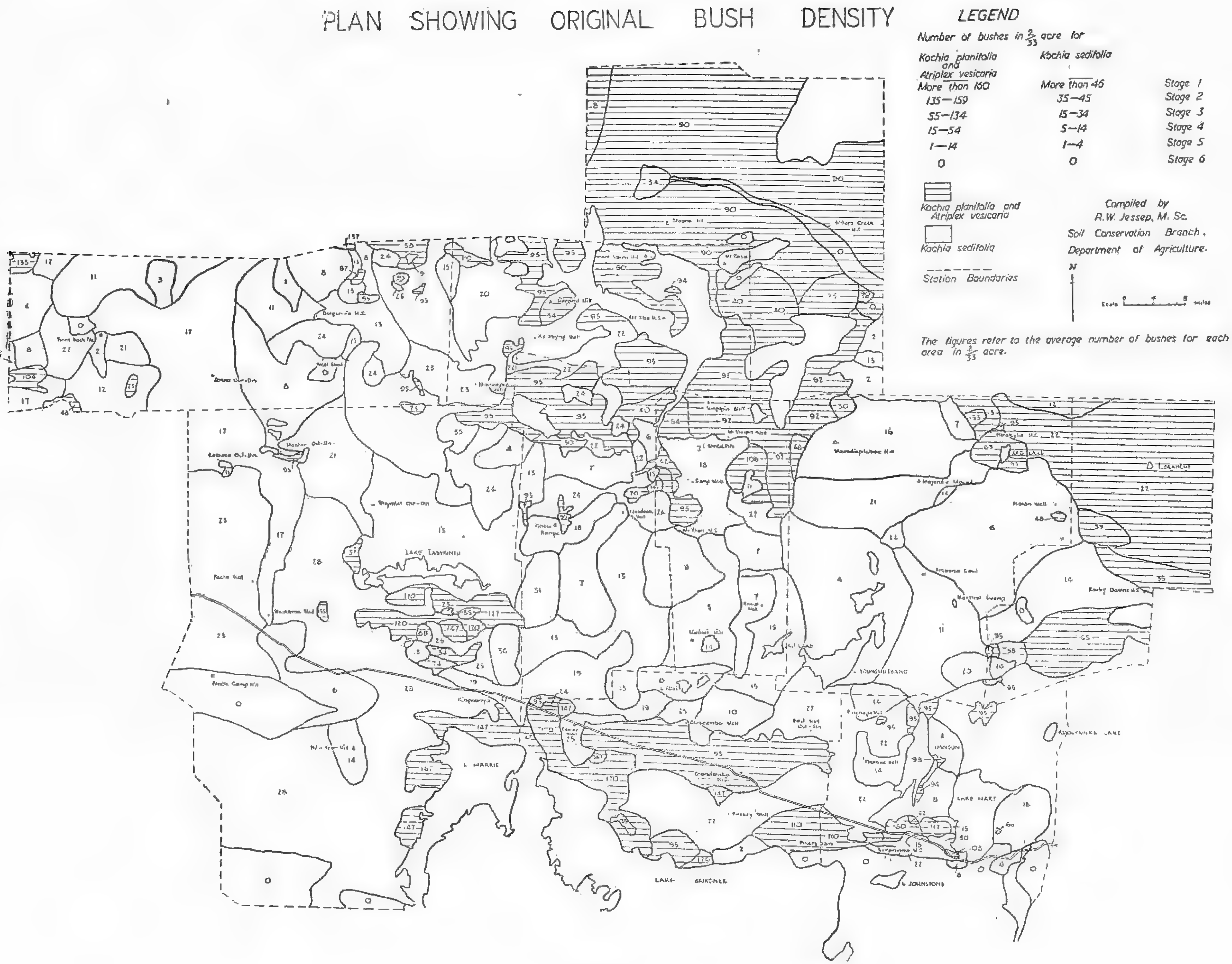
PLAN SHOWING ORIGINAL BUSH DENSITY
LEGEND
Number of bushes in $\frac{2}{33}$ acre for
Kochia planifolia and Atriplex vesicaria
Kochia sedifolia
More than 160 — More than 46 — Stage 1
135—159 — 35—45 — Stage 2
55—134 — 15—34 — Stage 3
15—54 — 5—14 — Stage 4
1—14 — 1—4 — Stage 5
0 — 0 — Stage 6
Kochia planifolia and Atriplex vesicaria
Kochia sedifolia
Station Boundaries
Compiled by R.W. Jessep, M. Sc.
Soil Conservation Branch, Department of Agriculture.
N
The figures refer to the average number of bushes for each area in $\frac{2}{33}$ acre.
LAKE LABYRINTH
L. HARRIS
LAKE GAIRDNER
LAKE HART
YOUNGHUSBAND

Fig. 12

to make cross-country traverses on compass bearings. Not all station tracks enable a correct impression to be formed of the general condition of the country they pass through. Thus they may tend to follow watercourses which contain only scattered *K. sedifolia* in the mulga and myall woodland country or sheep may be travelled down them to the woolshed for shearing. In these cases road traverses must be ignored in favour of cross-country observations.

The following is a typical record made in mulga-myall country (*Acacia aneura – A. brachystachya – – A. sowdenii – K. sedifolia* association complex):

Car speedometer reading when leaving Well No. 1, 65·2.

65·8	MyS	3 – 5	68·7	MyS	5
66·4	MyS	3 – 4	69·0	MS	3
66·7	M	6	69·2	MS	3 – 4
67·1	MyS	3	69·4	M	6
67·4	M	6			

Speedometer reading at Well No. 2, 69·4.

The speedometer readings refer to the points at which the different stages of bush density end, for example MyS 3 – 5 occurs from Well No. 1 (65·2) to 65·8, that is for ·6 mile. My is an abbreviation for myall, M for mulga and S for *Kochia sedifolia*. The figures in the right-hand column are the bush density stages; where two figures are recorded the first is the estimated density stage prior to stocking, while the second figure gives the present stage (thus 3 – 5 means originally Stage 3, now Stage 5). One figure in the right-hand column indicates that degeneration has not been sufficient to result in the country being placed in a lower density stage.

By multiplying the length of each stage over the total length of the transect by the number of bushes in the midpoint of the range for that stage and adding the results obtained for the different stages the average number of bushes in 2/33 acre for the area sampled by the transect, and hence its density stage, is obtained. If calculations are made using figures of present bush density and density prior to stocking the percentage of the original bush cover now remaining can be determined. Approximately 6,400 square miles of *Kochia sedifolia* dominant country were mapped quantitatively, and it has been calculated that this area retains 80% of its original bush cover. The *Atriplex vesicaria* and *Kochia planifolia* dominant areas (3,000 square miles) retain 65% of their original bush cover.

Fifty-seven plants of *Kochia sedifolia* on 2/33 acre was the maximum density of bluebush recorded. Actually stands containing 50 or more bluebushes are rarely encountered even where soil conditions are most favourable, so that for the country to fall into Stage 1 the bush density must usually be increased by the presence of bladder saltbush between the bluebushes. Most virgin stands of bluebush alone have a density equal to Stage 2. The change from Stage 1 to Stage 2, the first stage in the degeneration of bluebush country, is brought about by destruction of the bladder saltbush through grazing. Stages 1 and 2 are associated with Bon Bon and shallow Wirraminna soils, lower stages on these soils usually being the result of overgrazing. On Wilgena soil the bluebush count even under virgin conditions never exceeds 29 bluebushes on 2/33 acre.

A bluebush stand with a density equal to middle to higher Stage 3 appears to make an ideally balanced pasture, as sufficient bush is present to provide a drought-reserve of feed and to maintain soil stability, but at the same time competition is not so severe as to eliminate the growth of herbage and grass. Stages 4 and 5 occur naturally (that is without any degeneration through grazing) on the deeper sands and in watercourses.

Stands of bladder saltbush and low bluebush in the North-West only have a density equal to Stages 1 and 2 on the most favourable soil type, that is, Coondambo soil. On Twins soil, even under virgin conditions, the density is never greater than Stage 3 and the proportion of bluebush to saltbush in well-preserved country is about 7 to 1 on this soil. In Stage 1 stands of the two species on Coondambo soil the proportion of saltbush to low bluebush is about five to four, but in Stage 2 and 3 stands the proportion becomes about two to three, that is, grazing results in the destruction of a bigger proportion of saltbush than bluebush. Both species are about equally palatable but the saltbush is not as resistant to grazing. As with *Kochia sedifolia* an ideallly balanced pasture of low bluebush and bladder saltbush is apparently one with a bush density equal to middle to upper Stage 3.

DISCUSSION

The dominant trees and shrubs provide a drought reserve of feed and protection against soil erosion, but as the shrubs become defoliated under drought conditions, trees are more valuable than shrubs during a prolonged drought. As the trees are not destroyed by stocking with sheep at any rate, correct grazing management is centred upon maintenance of the shrub cover.

At the same time the balance between herbage, grass and shrubs is important. The carrying capacity of some bush stands has increased with stocking partly as a result of the benefits derived from judicious pruning of the bush through grazing but largely due to improvement in the shrub—herbage balance. Competition for moisture is so severe in dense bush stands that little herbage or grass appears between the bushes even in good seasons. Actually a paddock growing grass and bindyis (*Bassia* spp.) with little or no bush has a greater stock carrying capacity in good years than a well-bushed paddock, but during drought times stock losses occur earlier and they are heavier than in more densely bushed paddocks. A profitable line of scientific investigation would be to evaluate the merits of well-bushed, partly bushed and wholly denuded country in an endeavour to arrive at the most favourable balance between bush and herbage and grass. It would be possible perhaps to obtain an answer to the problem by carrying out studies on the chemical composition (particularly protein) and digestibility of the various species at different stages of growth. By relating these to the known palatabilities and to forage production the value of different pastures could be approximately determined.

The optimum density of bush stands is probably one equal to medium to higher Stage 3 (see quantitative estimates). Degeneration of bush country proceeds through lower Stage 3 to Stages 4 and 5 and ultimately to Stage 6, when no bush remains and the country carries a bindyi-dominant community. If grazing is still excessive the palatable bindyis are destroyed, leaving a grass-dominant stand whose protein supply is much lower than the bush-bindyi or bindyi stages. Ultimately overgrazing results in destruction of the palatable perennial grasses, leaving only ephemerals and unpalatable plants. Bladder saltbush (*Atriplex vesicaria*) is the most prolific seeder among the dominant shrubs. Bluebush (*Kochia sedifolia*) does not seed as heavily nor as frequently as saltbush but quite good seed crops are produced from time to time, whereas low bluebush (*K. planifolia*) produces little seed. Recolonization of a denuded paddock with bush is an extremely slow process even where the surrounding paddocks contain bush and hence a seed supply is available. Both saltbush and bluebush seed is equipped for wind dispersal, saltbush seed being contained within a bladdery fruit, while the bluebush fruit is winged. In spite of this, seed dispersal is poor and this is the cause of the slow recolonization. While scattered bushes remain through a paddock, however, regeneration can be quite rapid.

PLAN SHOWING PRESENT BUSH DENSITY

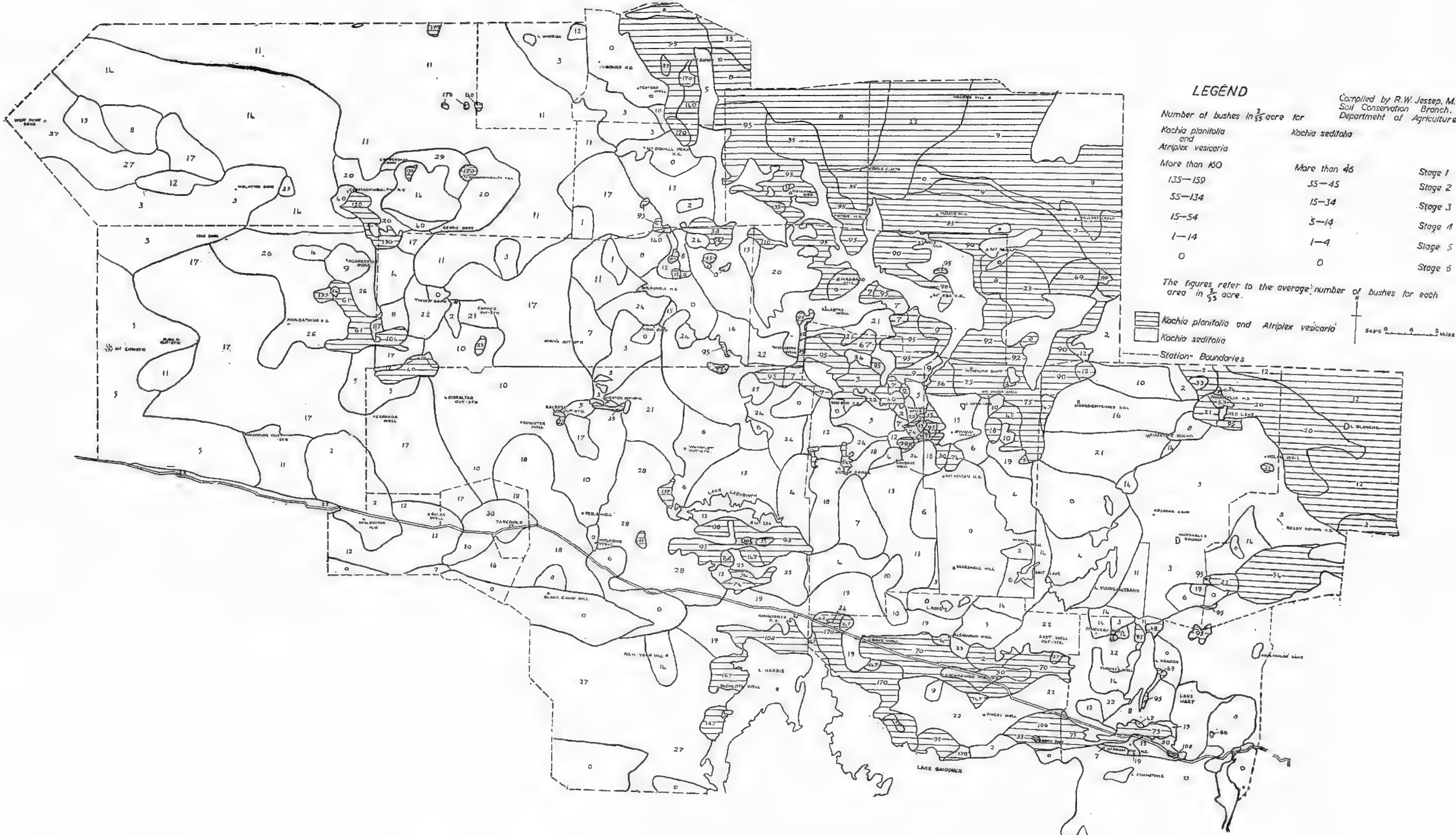

Fig. 13

It has already been pointed out that competition for moisture is an important factor in the arid plant communities, and in this connection it is noteworthy that most regeneration of bush commonly occurs where stocking has been heavy, for example, around sheep yards and in corners of paddocks where sheep tend to congregate. This increased regeneration is due to removal of grass and herbage by the sheep, thereby allowing more moisture for bush seedling growth. If it is necessary to thicken up a bush stand it follows that when the shrubs seed (and this only happens during good years) the country should be grazed heavily to reduce grass and herbage competition and then stocked lightly to allow seedling establishment to take place.

Reseeding trials on denuded country carried out at Bimbowrie station in the north-east of South Australia have indicated that saltbush can be successfully resown artificially. However, seasonal conditions must be favourable, and even then costs of reseeding are out of proportion to the value of the land. In these experiments the country was first furrowed, but the natural regeneration which occurs in sparsely bushed paddocks indicates that ploughing should not be necessary and that it should be possible to reseed denuded country by broadcasting seed.

Experimental research is necessary to determine the most economic paddock size or the correct number of watering points for a given area of country. It has been pointed out that at present many of the paddocks are far too large, as sheep only occasionally graze beyond a four-mile radius of the watering points under normal rates of stocking. Even within this four-mile radius the grazing intensity varies enormously, the area around the water being overgrazed, while the country beyond about two and a half miles is undergrazed. Much of the damage around the watering points results from the tramping of the sheep, and furthermore in large paddocks energy and hence feed wastage must occur through the sheep walking in to water and out again in search of feed. Smaller paddocks result in more uniform grazing and more efficient utilization of the country. Smaller mobs on each water reduce destruction of bush through tramping and also energy wastage through walking. Increased efficiency of utilization means that more sheep can be carried, but at the same time the costs of improvements and maintenance of improvements are increased. The problem is an economic one of balancing increased sheep numbers and hence returns against increased capital expenditure. With the very small paddocks used in the myall-bluebush country at Yudnapinna Research Station (Woodroffe, 1941), it has been found possible to graze at the rate of 75 sheep to the square mile without bush loss. It is not suggested that these quarter square mile paddocks are of practical size, but they do indicate that small paddocks enable a greater number of stock to be carried per square mile.

The size of the paddocks will naturally vary according to the carrying capacity of the country, and while pastoral areas have no fixed carrying capacity, nevertheless, the relative carrying capacities of the different plant associations are known for the North-West. The community with the greatest carrying capacity is the *Atriplex vesicaria – Kochia planifolia* association, and if its carrying capacity is 100 the other communities would be rated approximately as follows: *Acacia sowdenii – K. sedifolia* association (myall country) 55, *A. aneura – A. brachystachya* association (mulga country) 45, *A. aneura – A. brachystachya – A. tetragonophylla* association 40, *K. sedifolia* association 35, *Atriplex vesicaria – Ixiolaena leptolepis* association 35, *A. vesicaria – Bassia* spp. association 35, *K. planifolia – Bassia* spp. association 30, *Acacia linophylla – A. ramulosa* association 25, *Zygochloa paradoxa* association 20, *Kochia planifolia – Atriplex vesicaria – K. sedifolia* association 20, *A. rhagodioides* association 14, and *K. planifolia* association 14.

These ratings refer to the above communities only where they occur in the North-West, that is, on particular soils and in a particular climatic zone. Communities dominated by the same species in other parts of the pastoral country will not necessarily have the same relative carrying capacities.

As in all the pastoral country of South Australia, in the North-West there is no significant regeneration of the dominant trees, in this case the mulgas and myall. The factors responsible for this state of affairs are not fully known and progress in this direction requires knowledge of the autecology of the species. Possible contributing causes include seasonal conditions, absence of firing, lack of seed, competition with parent trees and effects of rabbits and stock. While loss of surface soil or deterioration in soil structure may be of some importance elsewhere, these factors can play no part in the sandy soil areas of the North-West. Regeneration is equally poor in the unoccupied country west of the area discussed in this paper.

Practically the only areas where established seedlings are found are where the country has been burned and in some swamps and watercourses. The seeds of these species have hard coats which are cracked by the fires and this may be at least partly responsible for the increased germination following burning. There is ample evidence throughout the mulga and myall woodlands that prior to white settlement much of the country had been burned. Most of these fires were probably started by blacks as a means of securing game. Firing no longer takes place to any extent.

The fact that other than in burned country regeneration is mostly restricted to swamps and watercourses suggests that moisture may be a limiting factor preventing widespread regeneration. The writer has read that regeneration of mulga following rolling is a common occurrence in Queensland where the average rainfall is between 11 and 13 inches. In South Australia, however, the mulga country is more arid receiving between 5 and 8 inches average annual rainfall. From the records available it appears that the little regeneration of mulga and myall that has occurred in this State has followed very heavy rains. Some interesting information in this connection has been supplied concerning a growth of young mulgas around the Bulgunnia homestead. This is situated in a depression and following 587 points of rain in 13 hours in February 1938 the homestead was flooded. Seedling mulgas "were first noticed around the homestead between January and June 1949". For the first six months of 1939 good rains were again experienced and the mulgas became firmly established. By July of 1946 they had reached a height of 2′ 6″ to 3′. However, some of them had appeared in the homestead garden where they were not dependent solely on natural rainfall but received additional water and these had reached a height of 8′–12′ by July 1946. All the records indicate that the young mulgas depending on natural rainfall have averaged an increased growth in height of 4″-6″ each year, but this is of no value as a measure of growth rate.

However, during the last five years there have been other rains similar to those of 1938 and a run of very good seasons has been experienced and yet practically no regeneration or even germination has been observed. An interesting point arises here. Mulgas (and myalls) must be very long-lived trees and yet some of the recent rains have resulted in so much water collecting in the swamps that many of the mature mulgas growing in them have been killed as a result of being flooded, that is, the swamps have recently contained water for a longer period than at any previous time during the life of the trees.

Competition with parent trees may play some part in preventing regeneration but this can no longer be considered a very important factor because, as pointed out earlier, about one-third of the mature mulgas and one-fifth of the mature

myalls have died. Tree death seems to be equally severe in the unoccupied country. It is interesting to note that competition among young myalls does not result in reduction in the density of the stand until the trees are well established. Thus in the country which was burned on Yudnapinna in 1922 there is now a very dense growth of "young" myalls, so much so that the trees are frequently touching, and yet no deaths have occurred and, in fact, all the trees appear very vigorous. In stands of mature myalls, on the other hand, the individual trees are quite scattered.

Lack of seed may well be an important factor preventing widespread regeneration. Although the mulgas in particular seed very abundantly during good years, an examination of the pods while still on the trees shows that a large proportion of the seeds are destroyed by insects. It is even more difficult to find undamaged seeds on the ground. Stock graze young mulgas under certain conditions but rarely to the extent of killing them, and furthermore regeneration is no better in the unstocked country. Rabbits, too, ringbark many of the young plants, but it is felt that neither stock nor rabbits are primarily responsible for the absence of widespread regeneration and that the fundamental fact is that there is actually a lack of germination. A combination of several factors is likely to be important, for example, seed supply and favourable seasonal conditions.

APPENDIX A

The Ecotypes of Saltbush (Atriplex vesicaria)

Wood (1936) has described three ecotypes of *A. vesicaria* from Koonamore station in the north-east of South Australia. The ecotype associated with soils containing heavy lime at shallow depth (Form A) is an erect woody bush. It occurs in the North-West on Wilgena and Bon Bon soils in association with bluebush (*Kochia sedifolia*), mulga and myall. Bladders are most commonly absent from the fruiting calyx or small bladders less than half the size of the bracts may be present. At Koonamore the average dimensions of this ecotype are height 32 cm and diameter 34 cm., but in the North-West both average height (37 cm.) and diameter (42 cm.) are slightly greater.

The second ecotype (Form B) is found on silty and sandy soils at Koonamore, but in the North-West is confined to Twins soil. As Wood (1936) points out fruits are generally without bladders, although occasionally bladders up to a third the size of the bracts are present. Form B is a very woody bush with a more erect growth habit than Form C. The bushes are larger than those of any other strain—at Koonamore they average 40 cm. high and have narrow lanceolate leaves, while in the North-West the leaves are obovate and the average height is 58 cm. and the average diameter is 73 cm.

Form C is found on silty soils at Koonamore and is a robust, rounded bush about 50 cm. high. Very large bladders are present on the calyx. In the North-West the form has comparatively small leaves and is restricted to soils containing clay within an inch or two of the surface (Mount Eba, Arcoona and Coober Pedy soils). Bushes growing on Mount Eba soil have an average height of 45 cm. and an average diameter of 52 cm. and larger bladders than those developed when the ecotype is growing on the other soils. On Coober Pedy and Arcoona soils the bushes are somewhat smaller (average height 35 cm. and average diameter 46 cm.).

A previously undescribed ecotype (Form D) is associated with deep sandy soils (Wirraminna type) in the North-West. It is characterised by an erect woody growth habit and by the presence of very large bladders on the fruiting calyx. Form D is a large ecotype having an average height of 55 cm. and an average diameter of 52 cm.

The natural soil preferences of the various ecotypes of saltbush should be considered when reseeding areas of country to this species. Better results are likely to be obtained by using Form A on calcareous soils, Form C on heavy-textured soils containing little or no lime and Form D on sandy soils.

Form C is both vigorous and a very prolific seeder, while Form A is also a prolific seeder and Form B is fairly prolific. Form D seeds less heavily than the other ecotypes and is not resistant to grazing.

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Numerous discussions with Dr. C. G. Stephens, Division of Soils, Commonwealth Scientific and Industrial Research Organisation, and Mr. K. Woodroffe, of the Department of Agronomy, Waite Institute, were very helpful.

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The writer lived at the various station homesteads scattered throughout the North-West while carrying out the field work, and without the co-operation and hospitality of the pastoralists the work could not have been done. For 18 months Mount Eba, formerly on the Adelaide to Darwin airline, was the centre from which the field work was carried out, and it is to Mr. and Mrs. Crombie of Mount Eba that the writer is most indebted. Mr. Crombie also provided facilities which enabled the writer to carry out maintenance work on the vehicle used on the survey. The writer is also extremely grateful to the following people for their hospitality and assistance: Mr. and Mrs. K. Neill of Bulgunnia, Mr. and Mrs. T. C. Young of Kingoonya, formerly of North Well, Mr. and Mrs. R. Jenkins of Wirraminna, Mr. and Mrs. J. Pick of Coondambo, Mr. and Mrs. C. Goode formerly of Malbooma, Mr. and Mrs. C. Greenfield of Billa Kalina, and Mr. and Mrs. F. Stoddart of Mount Vivian.

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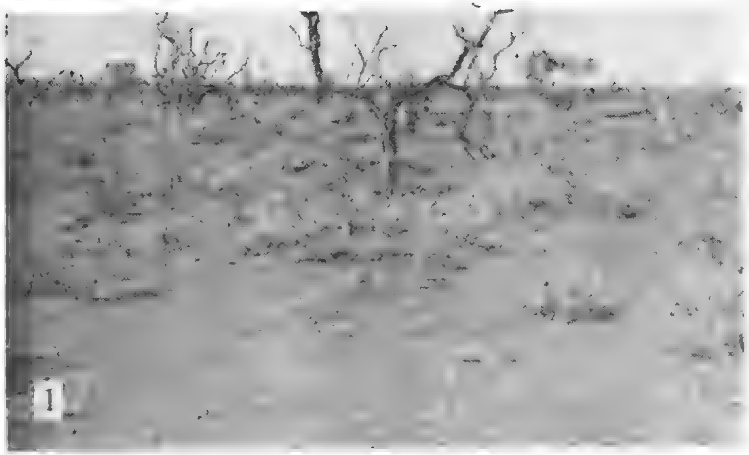

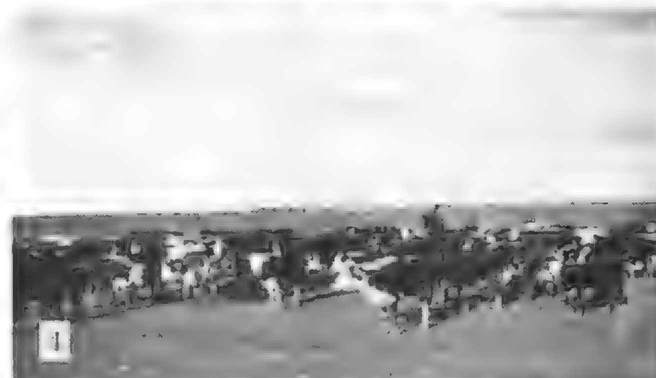

Fig. 1
Damage caused by a severe hail storm on Coondambo station. All the myall trees have been killed and the bluebush completely destroyed. Death results from complete defoliation through the breaking off of the smaller branches. The undershrub (*Kochia triptera* var. *erioclada*) has colonized the area after the destruction of the bluebush.

Fig. 2
Mulgas broken by a windstorm. Wirraminna station.

Fig. 3
Typical station sheep at Coondambo.

Fig. 4
A mob of cattle on Mabel Creek.

Fig. 1
A rare example of saltbush killed by rabbits. The photo was taken along the southern boundary of Coondambo station. In the foreground is a very good stand of saltbush which has survived in spite of quite heavy stocking. The country through the vermin fence is unoccupied and consequently never stocked. However, the northern shore of Lake Gairdner is only ¼ mile away and here very large numbers of rabbits breed, as they can obtain moisture by burrowing around the edge of the lake. The rabbits feed in the narrow strip of country between the lake and the vermin fence and have caused the death of the saltbush.

Fig. 2
A fig tree in the abandoned garden at old Mount Vivian homestead, which was almost completely barked by rabbits in 1948.

Fig. 3
Shrubs of *Cassia* eaten off by rabbits about a foot above the ground on Roxby Downs station during 1948. All the herbage and grass between the shrubs has been removed.

Fig. 4
An outcrop of granite on Bulgunnia station. The shrubs are granite wattle (*Acacia* [illegible]), a species always associated with granite outcrops.

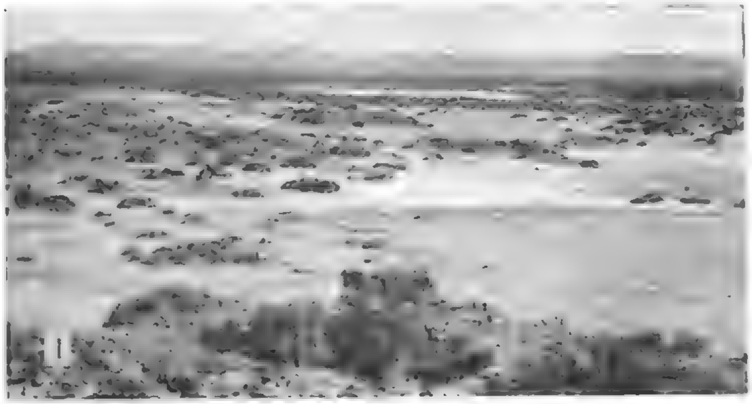

Fig. 1
The Denison Range south of Oodnadatta, looking towards its eastern side. The mounds in the foreground have been formed by springs which pour forth water from the Artesian Basin. The ground between the mound springs is always saline.

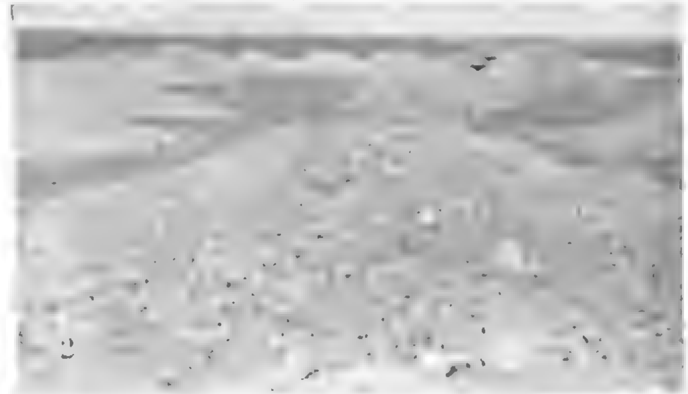

Fig. 2
Mounds of bleached Cretaceous shale around the opal diggings at Andamooka opal field.

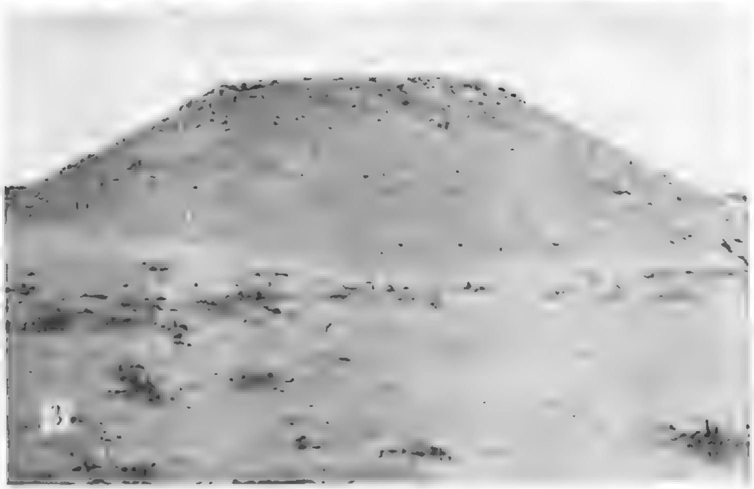

Fig. 3
A hill on Miller's Creek station consisting of siliceous limestone overlying bleached Cretaceous shale.

Fig. 4
Two to three inches of water in Lake Hart following exceptionally heavy rains.

Fig. 1

Flat-topped residual hills on W[illegible] station. The white background is the salt crust of Lake Hanson. The level horizon is the surface of the tableland country.

Fig. 2

Two residual hills on Miller's Creek station, showing white patches where the bleached shale is exposed and darker patches where the surface is covered with billy scree.

Fig. 3

Large boulders of billy which have been piled up to form a surveyor's trig. point on the top of Mount Paisley. The maximum thickness of the boulders, and hence the siliceous horizon from which they are derived, is two feet.

Fig. 4

A mound of gypsum (kopi) in the middle of a saltlake on Malbooma station. The gypsum deposit originally covered the whole of the lake, as indicated by the presence of other mounds on its surface. Under drier climatic conditions the gypsum was largely blown off the lake to form kopi dunes about its margins. The present surface of the lake is covered with a salt crust.

Fig. 1

Stuart's "range", composed of residuals of the Pliocene landscape, near Coober Pedy.

Fig. 2

The Devil's Playground, a large claypan on Billa Kalina station. The plants are swamp canegrass.

Fig. 3

A claypan on Ingomar station with a surface cover of billy gibbers.

Fig. 4

Gibber-covered puffs and shelves of Arcoona soil.

Fig. 1
Vertical photo of the Coober Pedy soil surface showing the mantle of billy pebbles and gibbers.

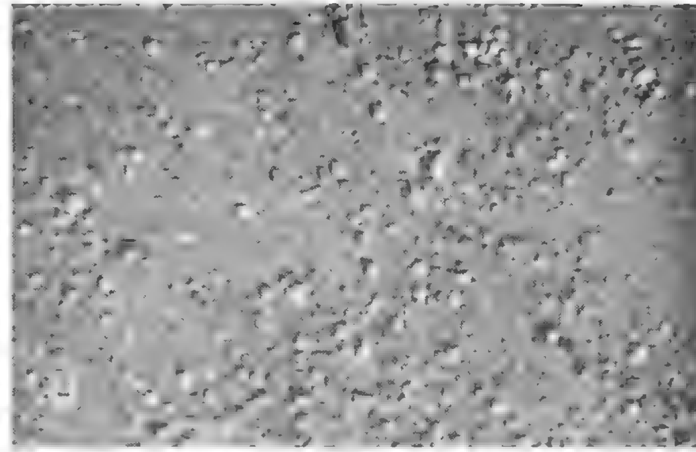

Fig. 2
Vertical photo of the Wilgena soil surface showing typical mantle of billy pebbles.

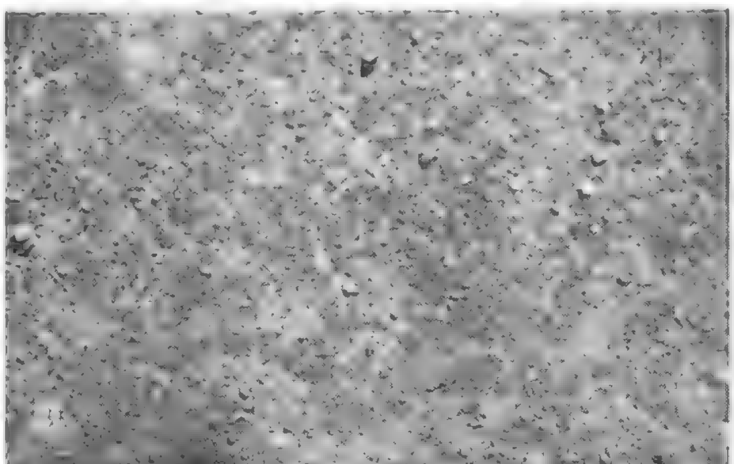

Fig. 3
Typical pebble cover on the surface of the Mount Eba soil. Vertical photo.

Fig. 4
Dense mulga woodland on Wirraminna station. The grass beneath the trees is mulga grass (*Aristida arenaria*).

Fig. 1
More open mulga woodland on McDouall Peak station. The grass is principally mulga grass. A few firebushes are present in the centre of the photograph. This country was previously stocked with cattle, with the result that the mulgas have been trimmed up to a considerable height.

Fig. 2
An ungrazed tree of myall, showing foliage sweeping to the ground.

Fig. 3
The myall - bluebush community on Roxby Downs station. Associated species is bindyi.

Fig. 4
A view of the bluebush community on Bon Bon soil, Wilgena station.

Fig. 1
Acacia linophylla — A. ramulosa association on a sandhill on Wirraminna station. The associated grass is *Aristida browniana.*

Fig. 2
Pines (*Callitris glauca*) on a sandhill on Parakylia station.

Fig. 3
Sandhill canegrass *(Zygochloa paradoxa)* on a dune near Anna Creek.

Fig. 4
Acacia aneura — A. brachystachya — A. tetragonophylla association on Mount Eba station. The associated species is principally mulga grass (*Aristida arenaria*). Note the bare patches, which are typical of the country even during good seasons.

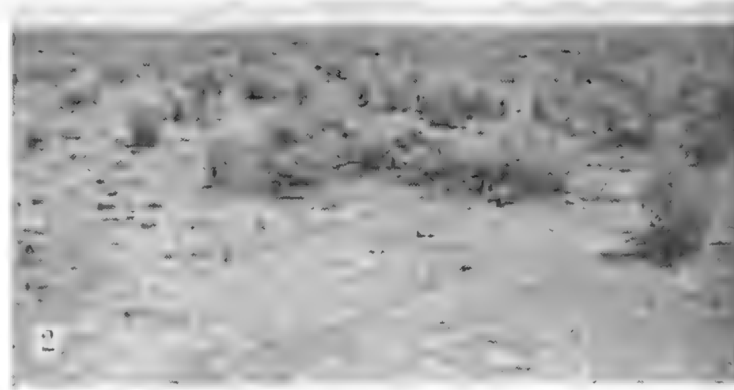

Fig. 1
The foreground, which now carries only *Bassia* spp., originally supported the *Kochia planifolia* – *Bassia* spp. association. In the background is a broad watercourse with species typical of the *Acacia aneura* – *A. brachystachya* – *A. tetragonophylla* association. Mount Eba station.

Fig. 2
Kochia planifolia association on Twins soil, Wirraminna station. Here the bushes are uniformly distributed.

Fig. 3
Kochia planifolia association, Miller's Creek station. Note that the bushes are restricted to slight depressions. The areas between (where shale is exposed) are devoid of growth even during good seasons

Fig. 4
Bladder saltbush and low bluebush on Coondambo soil, Wilgena station. Photo taken during very favourable seasonal conditions, but note absence of herbage and grass between bushes because of severe competition due to very high bush density. Mulga on watercourse in background.

Fig. 1
Atriplex vesicaria – Bassia spp. association on Coober Pedy soil, Coondambo station. Note that growth is practically restricted to the crabholes.

Fig. 2
A typical view of tableland country supporting bladder salt- [illegible]

Fig. 3
Atriplex rhagodioides (silver saltbush) association on tableland [illegible]

Fig. 4
[illegible] on a small creek near the shore of Lake Hanson.

Fig. 1
Coolibah and swamp canegrass (*Eragrostis australasica*) among the interlacing channels of the Miller's Creek watercourse.

Fig. 2
Coolibah fringing a waterhole in Miller's Creek. Billa Kalina station.

Fig. 3
Gidgea in a wadi in tableland country near Oodnadatta.

Fig. 4
Myall country with bush with density equal to Stage 1. Coondambo station, south of Pinery well. Bushes of bladder saltbush can be seen between the bluebushes.

Fig. 1
Myall country with bluebush with density equal to Stage 2. This country is adjacent to that in Plate XXIII, Figure 4, but there is no bladder saltbush between the bluebushes.

Fig. 2
Stage 4, bluebush country near Port Augusta.

Fig. 3
Stage 3, bluebush country near Port Augusta.

Fig. 4
Bladder saltbush and low bluebush with a density equal to Stage 2.

Fig. 1
Low bluebush with a density equal to Stage 3.

Fig. 2
Bladder saltbush and low bluebush with a density equal to Stage 4.

Fig. 3
Bladder saltbush and low bluebush with a density equal to Stage 5 (in the foreground and middle of the photo).

Fig. 4
A very large billy boulder exposed during dam-sinking at Yudnapinna Station. The siliceous horizon from which it was derived was approximately 2 feet in thickness. The rule is one metre long.

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WOODROFFE, K. 1941 Shrub Pastures under Low Rainfall. Jour. Aust. Inst. Agr. Sci., **3**

ROYAL SOCIETY OF SOUTH AUSTRALIA (INCORPORATED)

Receipts and Payments for the Year ended 30th September, 1950

RECEIPTS

	£	s.	d.	£	s.	d.
To Balance, 1st October, 1949				281	17	6
„ Subscriptions				158	16	8
„ Government Grant for Printing, etc.				400	0	0
„ Sale of Publications and Reprints:						
„ Highways and Local Government	41	12	0			
„ Sundries	39	6	9	80	18	9
„ Hire of Rooms				11	1	0
„ Half cost Repair to Chair				1	13	9
„ Interest				207	8	4
				£1,141	16	0

PAYMENTS

	£	s.	d.	£	s.	d.
By Transactions (Printing & Publishing Vol. 72, Pt. 2; Vol. 73, Pt. 1; Vol. 73, Pt. 2)				919	14	2
„ Reprints				38	12	6
„ Librarian				28	14	0
„ Printing, etc.				21	0	4
„ Postage				30	0	0
„ Sundries:						
Lighting	6	12	11			
Insurance	6	14	0			
Repairs	7	10	6			
Cleaning Rooms	13	5	0			
Hire Epidiascope	2	2	0			
Petties	3	4	0	39	8	5
„ Balances—30th September, 1950—						
„ Savings Bank of S.A.	11	13	0			
„ Bank of Australasia .... 56 10 7 Less Outstanding Cheques 1 5 0 / 2 12 0 = 3 17 0	52	13	7	64	6	7
				£1,141	16	0

Endowment Fund as at 30th September, 1950.

	£	s.	d.	£	s.	d.
1949—October 1—						
To Balance:						
Australian Inscribed Stock	6,010	0	0			
Savings Bank of S.A.	62	18	7	6,072	18	7
1950—September 30—						
To Interest:						
Inscribed Stock	199	14	6			
Savings Bank of S.A.	7	13	10	207	8	4
				£6,280	6	11

	£	s.	d.	£	s.	d.
1950—September 30—						
By Revenue Account:						
Balance				207	8	4
Australian Inscribed Stock	6,010	0	0			
Savings Bank of S.A.	62	18	7	6,072	18	7
				£6,280	6	11

Audited and found correct. The Stock and Bank Balances have been verified by certificates from the respective institutions.

F. M. ANGEL
N. S. ANGEL, A.U.A. Comm. } Hon. Auditors.

Adelaide, October, 1950

HERBERT M. HALE, Hon. Treasurer

AWARDS OF THE SIR JOSEPH VERCO MEDAL

1929 PROF. WALTER HOWCHIN, F.G.S.
1930 JOHN McC. BLACK, A.L.S.
1931 PROF. SIR DOUGLAS MAWSON, O.B.E., D.Sc., B.E., F.R.S.
1933 PROF. J. BURTON CLELAND, M.D.
1935 PROF. T. HARVEY JOHNSTON, M.A., D.Sc.
1938 PROF. J. A. PRESCOTT, D.Sc., F.A.I.C.
1943 HERBERT WOMERSLEY, A.L.S., F.R.E.S.
1944 PROF. J. G. WOOD, D.Sc., Ph.D.
1945 CECIL T. MADIGAN, M.A., B.E., D.Sc., F.G.S.
1946 HERBERT M. HALE

LIST OF FELLOWS, MEMBERS, ETC.

AS AT 30 MARCH 1951

Those marked with an asterisk (*) have contributed papers published in the Society's Transactions. Those marked with a dagger (†) are Life Members.

Any change in address or any other changes should be notified to the Secretary.

Note—The publications of the Society are not sent to those members whose subscriptions are in arrear.

Date of Election.

HONORARY FELLOWS

1945. *BLACK, J. M., A.L.S., (*Hon. causa*), 82 Brougham Place, North Adelaide—*Verco Medal*, 1930; Fellow, 1907-45; *Council*, 1927-31; *President*, 1933-34; *Vice-President*, 1931-33.
1945. *FENNER, C. A. E., D.Sc., 42 Alexandra Avenue, Rose Park, Adelaide—Fellow, 1917-45; *Council*, 1925-28; *President*, 1930-31; *Vice-President*, 1928-30; *Secretary*, 1924-25; *Treasurer*, 1932-33; *Editor*, 1934-37.
1949. *CLELAND, PROF. J. B., M.D., Dashwood Road, Beaumont, S.A.—*Fellow*, 1895-1949; *Verco Medal*, 1933; *Council*, 1921-26, 1932-37; *President*, 1927-28; 1940-41; *Vice-President*, 1926-27, 1941-42.

FELLOWS.

1946. ABBIE, PROF. A. A., M.D., D.Sc., Ph.D., University of Adelaide.
1927. *ALDERMAN, A. R., Ph.D., D.Sc., F.G.S., Div. Indus. Chemistry, C.S.I.R.O., Box 4331, G.P.O., Melbourne, Victoria—*Council*, 1937-42.
1931. ANDREW, REV. J. R., c/o Methodist Manse, Maitland.
1935. *ANDREWARTHA, H. G., M.Agr.Sc., D.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1950.
1935. *ANDREWARTHA, Mrs. H. V., B.Agr.Sc., M.S., (nee H. V. Steele), 29 Claremont Avenue, Netherby, S.A.
1929. *ANGEL, F. M., 34 Fullarton Road, Parkside, S.A.
1939. *ANGEL, MISS L. M., M.Sc., c/o University of Adelaide.
1945. *BARTLETT, H. K., L.Th., 15 Claremont Avenue, Netherby, S.A.
1950. BEASLEY, A. K., Harris Street, Marden, S.A.
1950. BECK, R. G., B.Ag.Sc., R.D.A., Linewood Park, Mittel, S.A.
1932. BEGG, P. R., D.D.Sc., L.D.S., Shell House, 170 North Terrace, Adelaide.
1928. BEST, R. J., D.Sc., F.A.C.I., Waite Institute (Private Mail Bag), Adelaide.
1934. BLACK, E. C., M.B., B.S., Magill Road, Tranmere, Adelaide.
1950. BONNIN, N. J., M.B., B.S., F.R.C.S. (Eng.), F.R.A.C.S., 144 Hill Street, North Adelaide, S.A.
1945. *BONYTHON, C. W., B.Sc., A.A.C.I., Romalo House, Romalo Avenue, Magill, S.A.
1940. BONYTHON, SIR J. LAVINGTON, B.A. (Camb.), 263 East Terrace, Adelaide.
1945. *BOOMSMA, C. D., M.Sc., B.Sc.For., 2 Celtic Avenue, South Road Park, S.A.
1947. BOWES, D. R., Ph.D., B.Sc., 51 Eton Street, Malvern.

Date of Election.

1939. BROOKMAN, Mrs. R. D. (nee A. Harvey), B.A., Meadows, S.A.
1945. BROUGHTON, A. C., Farina, S.A.
1948. BROWNING, T. O., B.Sc. (Syd.), Waite Institute (Private Mail Bag), Adelaide.
1944. *BURBIDGE, MISS N. T., M.Sc., C.S.I.R.O., Div. Plant Industry, P.O. Box 109, Canberra, A.C.T.
1923. BURDON, R. S., D.Sc., University of Adelaide—*Council*, 1946.
1922. *CAMPBELL, T. D., D.D.Sc., D.Sc., Dental Dept., Adelaide Hospital, Adelaide—*Council*, 1928-32, 1935, 1942-45; *Vice-President*, 1932-34; *President*, 1934-35.
1944. CASSON, P. B., B.Sc., For. (Adel.), 8 Benjafield Terrace, New Town, Hobart.
1929. CHRISTIE, W., M.B., B.S., Education Department, Social Services, 51 Pirie Street Adelaide—*Treasurer*, 1933-38.
1950. COALSTAD, S. E., B.Sc., 6 Hampton Street, Hawthorn, S.A.
1949. COLLIVER, F. S., Geology Department, University of Queensland.
1930. *COLQUHOUN, T. T., M.Sc., 10 French Street, Netherby, S.A.—*Secretary*, 1942-43.
1907. *COOKE, W. T., D.Sc., A.A.C.I., 4 South Terrace, Kensington Gardens, S.A.—*Council*, 1938-41; *Vice-President*, 1941-42, 1943-44; *President*, 1942-43.
1942. *COOPER, H. M., 51 Hastings Street, Glenelg, S.A.
1929. *COTTON, B. C., S.A. Museum, Adelaide—*Council*, 1943-46, 1948-49; *Vice-President*, 1949-50; *President*, 1950-.
1924. DE CRESPIGNY, SIR C. T. C., D.S.O., M.D., F.R.C.P., 219 North Terrace, Adelaide.
1950. DELAND, C. M., M.B., B.S., D.P.H., D.J.M., 29 Gilbert Street, Goodwood, S.A.
1941. DICKINSON, S. B., M.Sc., 52 Burnside Road, Kensington.
1930. DIX, E. V., Hospitals Department, Rundle Street, Adelaide, S.A.
1944. DUNSTONE, S. M. L., M.B., B.S., 124 Payneham Road, St. Peters, Adelaide.
1931. DWYER, J. M., M.B., B.S., 105 Port Road, Hindmarsh, S.A.
1933. *EARDLEY, MISS C. M., M.Sc., University of Adelaide—*Council*, 1943-46.
1945. *EDMONDS, S. J., B.A., M.Sc., 56 Fisher Terrace, Mile End, S.A.
1902. *EDQUIST, A. G., 19 Farrell Street, Glenelg, S.A.—*Council*, 1949-.
1944. FERRES, MISS H. M., M.Sc., 8 Taylor's Road, Mitcham, S.A.
1927. *FINLAYSON, H. H., 305 Ward Street, North Adelaide—*Council*, 1937-40.
1923. *FRY, H. K., D.S.O., M.D., B.S., B.Sc., F.R.A.C.P., Town Hall, Adelaide—*Council*, 1933-37; *Vice-President*, 1937-38, 1939-40; *President*, 1938-39.
1932. *GIBSON, E. S. H., M.Sc., 297 Cross Roads, Clarence Gardens, Adelaide.
1927. GODFREY, F. K., Box 951H, G.P.O., Adelaide.
1935. †GOLDSACK, H., Coromandel Valley, S.A.
1925. †GOSSE, SIR JAMES H., Gilbert House, Gilbert Place, Adelaide.
1910. *GRANT, PROF. SIR KERR, M.Sc., F.I.P., 56 Fourth Avenue, St. Peters, S.A.
1930. GRAY, J. T., Orroroo, S.A.
1933. GREAVES, H., 12 Edward Street, Glynde, S.A.
1904. GRIFFITH, H. B., Dunrobin Road, Brighton, S.A.
1948. GROSS, G. F., B.Sc., South Australian Museum, Adelaide—*Secretary*, 1950-.
1944. GUPPY, D. J., B.Sc., Mineral Resources Survey, Canberra, A.C.T.
1922. *HALE, H. M., Director S.A. Museum, Adelaide—*Verco Medal*, 1946; *Council*, 1931-34, 1950-; *Vice-President*, 1934-36, 1937-38; *President*, 1936-37; *Treasurer*, 1938-1950.
1949. HALL, D. R., Mern Merna, via Quorn, S.A.
1946. *HARDY, MRS. J. E. (nee A. C. Beckwith), M.Sc., Box 62, Smithton, Tas.
1944. HARRIS, J. R., B.Sc., 94 Archer Street, North Adelaide, S.A.
1947. HENDERSON, D. L. W., P.M.B., 20 Bourke, N.S.W.
1944. HERRIOT, R. I., B.Agr.Sc., Soil Conservator, Dept. of Agriculture, S.A.
1949. HOLLOWAY, B. W., B.Sc., 33 Kyre Avenue, Kingswood, S.A.
1924. *HOSSFELD, P. S., M.Sc., 132 Fisher Street, Fullarton, S.A.
1950. HOWARD, P. F., B.Sc., c/o Great Western Consolidated, Bullfinch, W.A.
1944. HUMBLE, D. S. W., 238 Payneham Road, Payneham, S.A.
1947. HUTTON, J. T., B.Sc., 18 Emily Avenue, Clapham.
1928. IFOULD, P., Kurralta, Burnside, S.A.
1942. JENKINS, C. F. H., Department of Agriculture, St. George's Terrace, Perth, W.A.
1918. *JENNISON, REV. J. C., 7 Frew Street, Fullarton, S.A.
1945. *JESSUP, R. W., M.Sc., 3 Alma Road, Fullarton, S.A.
1910. *JOHNSON, E. A., M.D., M.R.C.S., 1 Baker Street, Glenelg.
1950. JOHNS, R. K., B.Sc., Department of Mines, Flinders Street, Adelaide, S.A.
1921. *JOHNSTON, PROF. T. H., M.A., D.Sc., University of Adelaide—*Verco Medal*, 1935; *Council*, 1926-28, 1940-; *Vice-President*, 1928-31; *President*, 1931-32; *Secretary*, 1938-40; *Rep. Fauna and Flora Board*, 1932-39; *Editor*, 1943-45.
1939. †KHAKHAR, H. M., Ph.D., M.B., F.R.G.S., Khakhar Buildings, C.P. Tank Road, Bombay, India.

Date of Election.

1949. *KING, D., M.Sc., 44 Angwin Avenue, Blair Athol, S.A.
1933. *KLEEMAN, A. W., M.Sc., University of Adelaide—*Secretary*, 1945-48; *Vice-President*, 1948-1949, 1950-; *President*, 1949-50.
1922. LENDON, G. A., M.D., B.S., F.R.C.P., A.M.P. Building, King William Street, Adelaide.
1948. LOTHIAN, T. R. N., N.D.H. (N.Z.), Director, Botanic Gardens, Adelaide.
1949. LOWER, H. F., 7 Avenue Road, Highgate, S.A.
1931. *LUDBROOK, MRS. W. V. (nee N. H. Woods), M.A., Elimatta Street, Reid, A.C.T.
1948. McCULLOCH, R. N., M.B.E., B.Sc. (Oxon.), B.Agr.Sci. (Syd.), Roseworthy Agricultural College, S.A.
1938. MADDERN, C. B., B.D.S., D.D.Sc., Shell House, North Terrace, Adelaide.
1932. MANN, E. A., C/o Bank of Adelaide, Adelaide.
1939. MARSHALL, T. J., M.Agr.Sc., Ph.D., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1948-.
1905. *MAWSON, PROF. SIR DOUGLAS, O.B.E., D.Sc., B.E., F.R.S., University of Adelaide—*Verco Medal*, 1931; *President*, 1924-25, 1944-45; *Vice-President*, 1923-24, 1925-26; *Council*, 1941-43.
1950. MAY, L. H., B.Sc., 691 Esplanade, Grange, S.A.
1920. MAYO, THE HON. MR. JUSTICE, LL.B., K.C., Supreme Court, Adelaide.
1950. MAYO, G. M. E., B.Ag.Sc., Waite Institute (Private Mail Bag), Adelaide, S.A.
1943. McCARTHY, MISS D. F., B.A., B.Sc., 70 Halton Terrace, Kensington Park.
1945. †*MILES, K. R., D.Sc., F.G.S., Mines Department, Flinders Street, Adelaide.
1939. MINCHAM, V. H., Hammond, S.A.
1925. †MITCHELL, PROF. SIR W., K.C.M.G., M.A., D.Sc., Fitzroy Ter., Prospect, S.A.
1933. MITCHELL, PROF. M. L., M.Sc., University, Adelaide.
1938. MOORHOUSE, F. W., M.Sc., Chief Inspector of Fisheries, Flinders Street, Adelaide.
1936. *MOUNTFORD, C. P., 25 First Avenue, St. Peters, Adelaide.
1944. MURRELL, J. W., Engineering and Water Supply Dept., Port Road, Thebarton, S.A.
1944. NEAL-SMITH, C. A., B.Agr.Sci., 16 Gooreen Street, Reid, Canberra, A.C.T.
1944. NINNES, A. R., B.A., 62 Sheffield Street, Malvern, S.A.
1945. *NORTHCOTE, K. H., B.Agr.Sc., A.I.A.S., Waite Institute (Private Mail Bag), Adelaide.
1930. OCKENDEN, G. P., B.A., c/o Flinders Street Practising School, Flinders St., Adelaide.
1947. *OPHEL, I. L., 65 Fifth Avenue, St. Peters, S.A.
1913. *OSBORN, PROF. T. G. B., D.Sc., Department of Botany, Oxford, England—*Council*, 1915-20, 1922-24; *President*, 1925-26; *Vice-President*, 1924-25, 1926-27.
1937. *PARKIN, L. W., M.Sc., c/o North Broken Hill Mining Co., Melbourne, Victoria.
1949. PARKINSON, K. J., B.Sc., 8 Mooreland Avenue, Beverley, S.A.
1945. PATTISON, G., 68 Partridge Street, Glenelg, S.A.
1929. PAULL, A. G., M.A., B.Sc., 10 Milton Avenue, Fullarton, S.A.
1926. *PIPER, C. S., D.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1941-43; *Vice-President*, 1943-45, 1946-47; *President*, 1945-46.
1948. POWRIE, J. K., B.Sc., C.S.I.R.O., Division of Biochemistry, University, Adelaide.
1947. POYNTON, J. O., M.D., M.A., Ch.B., M.R.C.S., L.R.C.P., Institute Medicine, Vet. Science, Frome Road, Adelaide.
1949. PRAITE, R. G., 81 Park Terrace, North Unley, S.A.
1925. *PRESCOTT, PROF. J. A., C.B.E., D.Sc., A.I.C., Waite Institute (Private Mail Bag), Adelaide—*Verco Medal*, 1938; *Council*, 1927-30, 1935-39; *Vice-President*, 1930-32; *President*, 1932-33.
1926. PRICE, A. G., C.M.G., M.A., Litt.D., F.R.G.S., 46 Pennington Terrace, North Adelaide.
1945. PRYOR, L. D., M.Sc., Dip.For., 32 La Perouse Street, Griffith, N.S.W.
1950. *RATTIGAN, J. H., B.Sc., Bureau of Mineral Resources, Melbourne Building, Canberra, A.C.T.
1944. RICEMAN, D. S., M.Sc., B.Agr.Sc., C.S.I.R.O., Division of Nutrition, Adelaide.
1947. RIEDEL, W. R., B.Sc., Oceanographic Institute, Gottenburg, Sweden.
1948. *RIMES, G. D., B.Sc., 24 Winston Avenue, Clarence Gardens, S.A.
1947. RIX, C. E., 42 Waymouth Avenue, Glandore, S.A.
1946. *ROBINSON, E. G., M.Sc., 42 Riverside Drive, Sudbury, Ontario, Canada.
1950. RUDD, PROF. E. A., B.Sc., A.M., University, Adelaide, S.A.
1945. RYMILL, J. R., Old Penola Estate, Penola, S.A.
1944. *SANDARS, MISS D. F., M.Sc., University of Queensland, Brisbane, Queensland.
1950. SAUNDERS, F. L., 79 Winchester Street, Malvern, S.A.
1933. SCHNEIDER, M., M.B., B.S., 175 North Ter., Adelaide.
1946. *SEGNIT, E. R., M.Sc., C.S.I.R.O., Division of Industrial Chemistry, Box 4331, G.P.O., Melbourne, Victoria.

Date of Election.

1924. *SEGNIT, R. W., M.A., B.Sc., Engineering and Water Supply Department, Victoria Square, Adelaide—*Secretary*, 1930-35; *Council*, 1937-38; *Vice-President*, 1938-39, 1940-41; *President*, 1939-40.
1925. *SHEARD, H., Port Elliot, S.A.
1936. *SHEARD, K., Fisheries Research Div. C.S.I.R.O., University of W.A., Nedlands, W.A.
1945. SHEPHERD, J. H., M.Sc., B.A., c/o Anglo-Westralian Mining Pty. Ltd.
1934. SHINKFIELD, R. C., Salisbury, S.A.
1924. SIMPSON, F. N., Pirie Street, Adelaide.
1949. SIMPSON, D. A., M.B., B.S., 42 Lockwood Road, Burnside, S.A.
1941. *SMITH, T. LANGFORD-, B.Sc., Department of Post-War Reconstruction, Canberra, A.C.T.
1941. SOUTHCOTT, R. V., M.B., B.S., 12 Avenue Road, Unley Park, S.A.
1936. SOUTHWOOD, A. R., M.D., M.S. (Adel.), M.R.C.P., Wootoona Ter., Glen Osmond, S.A.
1947. *SPECHT, R. L., M.Sc., 15 Main Road, Richmond, S.A.
1936. *SPRIGG, R. C., M.Sc., Mines Department, Flinders Street, Adelaide.
1947. SPURLING, M. B., B.Ag.Sc., Agricultural College, Roseworthy, S.A.
1949. *SPRY, A. H., B.Sc., 63 LeFevre Terrace, North Adelaide, S.A.
1938. *STEPHENS, C. G., D.Sc., Waite Institute (Private Mail Bag), Adelaide.
1935. SRRICKLAND, A. G., M.Agr.Sc., 11 Wootoona Terrace, Glen Osmond, S.A.—*Council*, 1947.
1932. SWAN, D. C., M.Sc., Waite Institute (Private Mail Bag), Adelaide—*Secretary*, 1940-42; *Vice-President*, 1946-47, 1948-49; *President*, 1947-48.
1948. SWANN, F. J. W., 38 Angas Road, Lower Mitcham, S.A.
1934. SYMONS, I. G., 35 Murray Street, Lower Mitcham, S.A.—*Editor*, 1947-.
1929. *TAYLOR, J. K., B.A., M.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1940-43, 1947-.
1950. TAYLOR, G. H., B.Sc., Department of Mines, Old Legislative Council Building, North Terrace, Adelaide, S.A.
1948. *THOMAS, I. M., M.Sc. (Wales), University, Adelaide—*Secretary*, 1948-50; *Council*, 1950-.
1938. *THOMAS, MRS. I. M. (nee P. M. Mawson), M.Sc., 36 King Street, Brighton.
1940. THOMSON, CAPT. J. M., 135 Military Road, Semaphore South, S.A.
1923. *TINDALE, N. B., B.Sc., South Australian Museum, Adelaide—*Secretary*, 1935-36; *Council*, 1946-47; *Vice-President*, 1947-48, 1949-50; *President*, 1948-49.
1945. TIVER, N. S., M.Sc., B.Agr.Sc., Waite Institute (Private Mail Bag), Adelaide.
1937. *TRUMBLE, PROF. H. C., D.Sc., M.Agr.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1942-1945; *Vice-President*, 1945-46, 1947-48; *President*, 1946-47.
1925. TURNER, D. C., Brookman Buildings, Grenfell Street, Adelaide.
1950. VIETCH, S. T., Port Lincoln, S.A.
1912. *WARD, L. K., I.S.O., B.A., B.E., D.Sc., 22 Northumberland Avenue, Tusmore—*Council*, 1924-27, 1933-35; *Vice-President*, 1927-28; *President*, 1928-30.
1941. *WARK, D. C., M.Agr.Sc., Div. Plant Industry, C.S.I.R.O., Canberra, A.C.T.
1936. WATERHOUSE, MISS L. M., 35 King Street, Brighton, S.A.
1939. *WEEDING, REV. B. J., 5 York Street, Henley Beach.
1949. *WEGENER, C. F., B.Sc., Department Mines, Flinders Street, Adelaide, S.A.
1946. WHITTLE, A. W. G., B.Sc., Mines Department, Flinders Street, Adelaide.
1950. WILLIAMS, L. D., "Dumosa," Meningie, S.A.
1946. *WILSON, A. F., M.Sc., University of W.A., Nedlands, W.A.
1938. *WILSON, J. O., C.S.I.R.O., Division of Nutrition, Adelaide.
1930. *WOMERSLEY, H., F.R.E.S., A.L.S. (*Hon. causa*), S.A. Museum, Adelaide—*Verco Medal*, 1943; *Secretary*, 1936-37; *Editor*, 1937-43, 1945-47; *President*, 1943-44, *Vice-President*, 1944-45; *Rep. Fauna and Flora Protection Committee*, 1945.
1944. *WOMERSLEY, H. B. S., M.Sc., University of Adelaide.
1944. WOMERSLEY, J. S., B.Sc., Lae, New Guinea.
1923. *WOOD, PROF. J. G., D.Sc., Ph.D., University of Adelaide—*Verco Medal*, 1944; *Council*, 1938-40; *Vice-President*, 1940-41, 1942-43; *Rep. Fauna and Flora Board*, 1940-; *President*, 1941-42; *Council*, 1944-48.
1950. WOODARD, G. D., 20 Kensington Road, Leabrook, S.A.
1943. WOODLANDS, HAROLD, Box 989 H, G.P.O., Adelaide.
1945. WORTHLEY, B. W., B.A., M.Sc., A. Inst. P., University, Adelaide.
1948. *WYMOND, A. P., B.Sc., 4 Woodley Road, Glen Osmond, S.A.
1949. YEATES, J. N., L.S., A.M.I.E., A.M.I.M.E., Richards Buildings, 99 Currie Street, Adelaide, S.A.
1944. ZIMMER, W. J., Dip.For., F.L.S. (Lon.), 7 Rupert Street, Footscray West, W.12, Vic.

AUTHOR AND SUBJECT INDEX VOLUME 74

[Names in italics denote that the described forms are new to science.]

CONTENTS

PART I

PART II